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Lung cancer mortality in Australia in the twenty-first century: How many lives can be saved with effective tobacco control?

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ABSTRACT

Objectives: To estimate the number of past and future lung cancer deaths that have already been averted by tobacco control initiatives in Australia, and to estimate the number of additional deaths averted under various smoking scenarios.

Methods: We predicted lung cancer mortality rates and case numbers to 2100 using a previously validated generalized linear model based on age, birth cohort and population cigarette smoking exposure. We estimated the impact of various tobacco control scenarios: 'actual tobacco control' (incorporating the aggregate effect of past and current taxation, plain packaging, mass media campaigns and other initiatives) and scenarios where 10%, 5% and 0% smoking prevalence was achieved by 2025, all of which were compared to a counterfactual scenario with the highest historical smoking consumption level continuing into the future as if no tobacco control initiatives had been implemented.

Results: Without tobacco control, there would have been an estimated 392,116 lung cancer deaths over the period 1956–2015; of these 20% (78,925 deaths; 75,839 males, 3086 females) have been averted due to tobacco control. However, if past and current measures continue to have the expected effect, an estimated 1.9 million deaths (1,579,515 males, 320,856 females; 67% of future lung cancer deaths) will be averted in 2016–2100. If smoking prevalence is reduced to 10%, 5% or 0% by 2025, an additional 97,432, 208,714 or 360,557 deaths could be averted from 2016 to 2100, respectively.

Conclusion: Tobacco control in Australia has had a dramatic impact on the number of people dying from lung cancer. Several hundred thousand more lung cancer deaths could be averted over the course of the century if close-to-zero smoking prevalence could be achieved in the next decade.

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1. Introduction

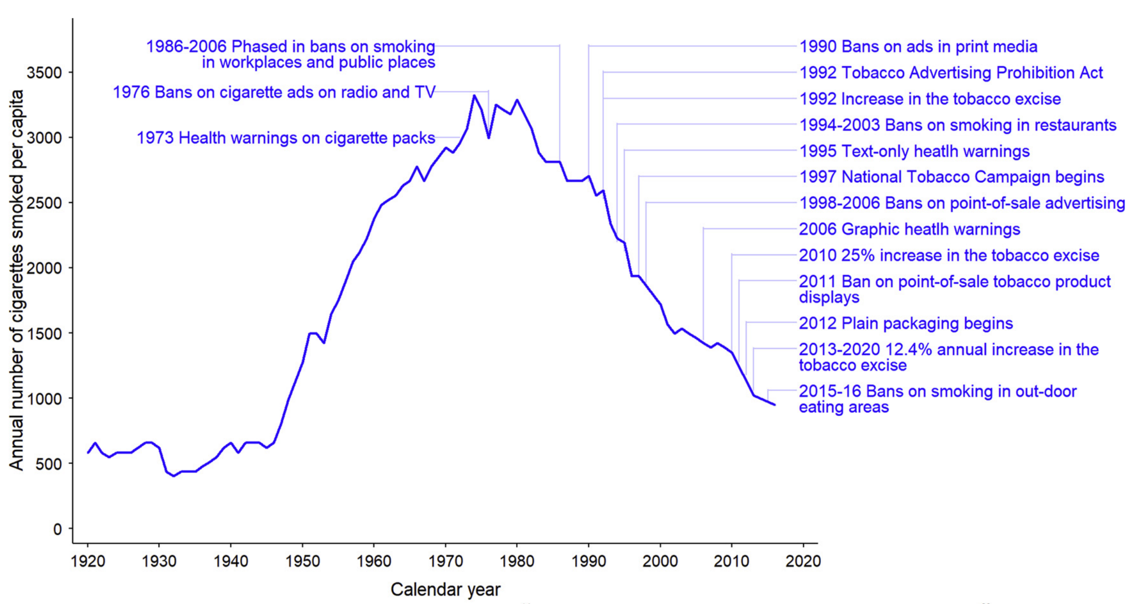
Evidence to date shows that tobacco control interventions implemented in Australia have been successful in reducing the prevalence of smoking [1–4] and there have been subsequent reductions in lung cancer mortality [5]. Nonetheless, lung cancer continues to be the biggest cause of cancer death, indicating that additional progress needs to be made to further reduce the impact of smoking [6]. Projections of lung cancer mortality based on different tobacco control scenarios quantify the effectiveness of tobacco control policies and may provide some insight into the effects of changes in smoking behaviour in the population [7,8]. In this paper we explicitly model the prevalence of smoking and the number of cigarettes smoked in the population, which provides a surrogate estimate of the impact of tobacco control strategies, increased awareness, and other possible contributing factors; for convenience, we refer to the different scenarios as 'tobacco control scenarios' throughout the paper.

We have previously developed and validated a statistical model which incorporated tobacco consumption as a factor in the projection of lung cancer mortality rates up to 2040 [9]. These projections reflected the effects of both past and present tobacco control interventions implemented up to 2016 including tobacco taxation, bans on tobacco advertising, smoke-free legislation, packaging restrictions, point-of-sale legislation, and anti-tobacco mass media campaigns (Fig. 1). We assumed that, given the continuation of current tobacco control measures, recent trends in tobacco exposure will continue into the future (this is hereafter referred to as the 'actual tobacco control' scenario). As we have previously shown, there is a 26–29 year delay between changes in population smoking patterns and substantial changes in the lung cancer mortality rate in the population [9]. Hence, the first aim of the current study was to extend the projections to 2100, to estimate the full benefits of past and present tobacco control on lung cancer mortality rates by comparing the actual tobacco control scenario to a counterfactual scenario in which smoking prevalence and cigarette consumption remained at the highest historical levels (hereafter referred to as the 'no tobacco control' scenario). We estimated the number of deaths from lung cancer that have been averted over the period 1956–2015 due to actual tobacco control interventions, and projected the number of lung cancer deaths that could potentially be averted in 2016–2100. The second aim was to assess the potential impacts of changes in smoking behaviour on future lung cancer mortality, by examining five possible scenarios, including three which assumed a lower smoking prevalence by 2025 (10%, 5% and 0% prevalence), and two hypothetical scenarios which represented a possible cessation or reversion of tobacco control effects: (1) no change in smoking patterns after 2016 and; (2) smoking prevalence level reverted to the 2005 level by 2025. All these scenarios were compared to both the no tobacco control and the actual tobacco control scenarios.

2. Methods

2.1. Data sources

Lung cancer mortality data by sex, age and calendar year for 1956–2015 were obtained from the World Health Organization (WHO) Mortality Database (MDB) [10], and the corresponding Australian population data by sex, 5-year age group and calendar year from 1956 to 2100 were obtained from the Australian Historical Population Statistics and Population Projections by the Australian Bureau of Statistics (ABS) [11,12]. All age-standardized lung cancer mortality rates were standardized to the WHO World Standard Population [13]. Smoking data for age 15 years or above in 1945–2004 were obtained from the International Smoking Statistics (ISS) Web Edition 2016, which includes data from the National Drug Strategy Household Survey (NDSHS) [14], and these were integrated with the more recent NDSHS data for 2007–2016 [15–18]. Detailed descriptions of the data sources for smoking exposure have been described previously [9]. Smoking prevalence was defined as the percentage of the population who currently smoke cigarettes of any tobacco products at any frequency in the previous 12 months. Annual number of cigarettes smoked per person was defined as the number of cigarettes smoked per person per year averaged over both smokers and non-smokers in the population. Cigarette tar exposure per capita is a measure of the population's cigarette exposure which was calculated by number of cigarettes smoked multiplied by the average tar content per cigarette, which is assumed to remain constant after 2003 [9]. Sex-age-period-specific smoking variables in Australia were re-constructed backwards to 1920 and forwards to 2020 [9], and the same methods were used to extend these projections forward to 2080. As data on smoking behaviour for pre-adolescents and young adolescents is very scarce, and is not included in the



Sources: International Smoking Statistics, Web edition 2016.[14] Scollo, MM and Winstanley, MH. Tobacco in Australia 2016.[23] Australian Government Department of Health, Tobacco Control key facts and figures 2017.[24]

Fig. 1. Timeline for tobacco control and annual number of cigarettes smoked per capita 1920–2016 in Australia.

sales adjustment calculations in the ISS, we did not include smoking information for those aged less than 15 years. Although smoking clearly does occur below this age, it is at a much lower level than for the adult population [15–17,19].

2.2. Statistical analysis

In our previous work we applied and validated a generalized linear model (GLM) with Poisson distribution to model sex-age-period specific lung cancer mortality rates as a function of age, birth cohort and sex-age-period-specific cigarette tar exposure, fitting models for males and females separately [9]. The final fitted model for each sex can be presented as a parsimonious equation:

$$lnD_{ij} = lnN_{ij} + \alpha Age_i + \beta CTC_{ij-L} + \gamma Cohort_{l-i+j} + \varepsilon_{ij}$$

where D_{ij} denotes the number of deaths from lung cancer for the *i*th age group during the *j*th calendar period; N_{ij} denotes the number at risk in the population for the *i*th age group during the *j*th calendar period; Age_i denotes the age group 30–34, 35–39, …, ≥ 85 years; $Cohort_{l-i+j}$ denotes the birth cohorts 1875–1879, 1880–1884, …, 1980–1984; CTC_{ij-L} denotes the sex-age-period-specific cigarette tar exposure in the population for the *i*th age group during *j-L*th calendar period, which is lagged by *L* years (26 years for males and 29 years for females) [9]. Due to the lag between cigarette exposure and mortality, these fitted models are considered to represent the lung cancer mortality based on the tobacco control programs in place 26–29 years prior to each period. These models assumed that the age effects remained constant over time [8,9,20]. In the current study we used the above model to project sex-age-period specific lung cancer mortality rates for 2016–2100 under different tobacco control scenarios by using scenario-specific projections of cohort effects and cigarette tar exposure linked to a specific smoking prevalence. As the average tar content per cigarette is assumed to be constant since 2003 [9], the cigarette tar exposure measure modelled in the current study refer to the sex-age-period-specific smoking prevalence and the number of cigarettes smoked per capita. Details of each scenario are described below and summarized in Appendix 1.

2.2.1. Actual tobacco control scenario

Estimated number of cigarettes smoked per capita from 2017 to 2080 was based on a log-linear projection of recent trends for the number of cigarettes smoked per capita, extending previously published estimates beyond 2020 [9]. Previous studies indicate that cohort effects reflect the smoking behaviour of each generation in the population [21,22], and that cigarette tar exposure is the most significant predictor of cohort effects amongst the various measures of smoking that were available for this study [9]. We therefore estimated the future cohort effects as a function of sex-cohort-specific 'lifetime' cigarette tar exposure using linear regression of past cohort effects on sex-cohort-specific cigarette tar exposure, as previously validated [9].

Based on recent trends showing continued gains from past tobacco control interventions already implemented, we assumed that the current trends in smoking behaviour implicitly capture the ongoing effects of the tobacco control measures which have occurred and will continue in the immediate future, including the annual tax increases from 2013-2020. The prevalence of smoking for both males and females is estimated to decrease gradually from 22.5% in 2005, to 17.5% in 2016, 14.4% in 2025, 10% in 2045, and 5% in 2080 for males, and from 18.6% in 2005, to 13.0% in 2016, 10.3% in 2025, 10% in 2030, and 5% in 2050 for females (Appendix 2). In this scenario, the total smoking prevalence in 2025, based on existing trends, is estimated to be 12.3%.

2.2.2. No tobacco control scenario

In the counterfactual 'no tobacco control' scenario the cohort effects and the cigarette tar exposure per capita were assumed to remain constant after reaching their highest historical levels. The birth cohorts with the highest levels of cigarette tar exposure were those born in the 1920s for males and the 1940s for females. Annual number of cigarettes smoked per capita was highest in the 1960s for males and in the 1980s for females [9].

2.2.3. Zero smoking prevalence by 2025 scenario

Although achieving a prevalence of 0% by 2025 appears ambitious, we modelled the impact of this in order to quantify the gains possible if such a 'stretch goal' could be achieved. This scenario was intentionally designed to gain an understanding of the maximum potential impact due to substantial changes in tobacco control over the next few years and the earliest time at which this could be achieved. To achieve zero smoking prevalence for adults aged 15 years and above by 2025, we assumed that all smokers born before 2010 will have quit smoking by 2025, and that no individual born after 2010 would initiate smoking. Hence, we set the cigarette tar exposure level to be zero from 2025 and the cohort effects from 2010 onwards were assumed to be equal to the cohort effects for past birth cohorts that were not exposed to tobacco smoking. We used log-linear interpolation to estimate tar exposure between 2017 and 2025 and used linear interpolation to estimate the cohort effects between 1980 and 2010.

Due to the limited historical data on both lung cancer mortality prior to the 1950s, and on smoking exposure prior to the 1920s, direct data on birth cohort effects prior to the introduction of cigarettes were not readily available. To estimate these cohort effects, we examined the relationship between tobacco control interventions and the trends in overall cigarette consumption per capita from 1900 to 2016 for Australia, the United States (US) and the United Kingdom (UK) (Appendix 3) [14,23–27]. The overall number of cigarettes smoked per capita was considered to be very low in the 1900 s–1910 s in the US. Assuming a similar pattern in Australia, and given the observed peak of cigarette consumption around the age of 35 years [9], the 1850 birth cohort was used as a surrogate for a past birth cohort that was not exposed to tobacco products. We estimated the cohort effects for 1850 based on backward projections of the observed cohort effects for 1875–1910 as a function of the lifetime cigarette tar exposure (R^2 = 0.94 for males and 0.95 for females for the observed data), assuming that the lifetime cigarette tar exposure was zero for the 1850 birth cohort.

2.2.4. Other tobacco control scenarios

We also examined four other possible scenarios, including assuming a smoking prevalence of 5% or 10% by 2025, assuming no change in smoking patterns after 2016, and a scenario assuming that in 2025 the smoking prevalence had reverted to the level observed in 2005. The time point at which a specific level of smoking prevalence would be reached with the 'actual tobacco control' scenario is hereafter referred to as the 'equivalent time' for alternate scenarios (e.g. the equivalent time for 5% smoking prevalence by 2025 is 2080 for males and 2050 for females). For each of the smoking prevalence scenarios for 2025 (5%, 10%, 2016 levels, or 2005 levels) we calculated the annual number of cigarettes smoked and tar exposure per capita corresponding to the equivalent time from the 'actual tobacco control' scenario, separately for males and females (see Appendix 1). The cigarette tar exposure levels for 2025 and each year thereafter in the given scenario were set to the values given by the 'actual tobacco control' scenario from the corresponding equivalent period and following years accordingly.

For the cohort effects we anchored the calculations to the 1990 birth cohort, as cohort effects generally peak at roughly 35 years of age [9], which corresponds to the 1990 birth cohort for 2025. Hence, we set the cohort effect for 1990 as equal to the effects of the cohort turning 35 at the equivalent time in the 'actual tobacco control' scenario, so that the sex-cohort-specific lifetime cigarette tar exposure levels correspond to each of the smoking prevalence scenarios (e.g. the 2045 birth cohort for 5% prevalence for males and the 2015 birth cohort for 5% prevalence for females). The cohort effects for 1990–2070 were estimated using

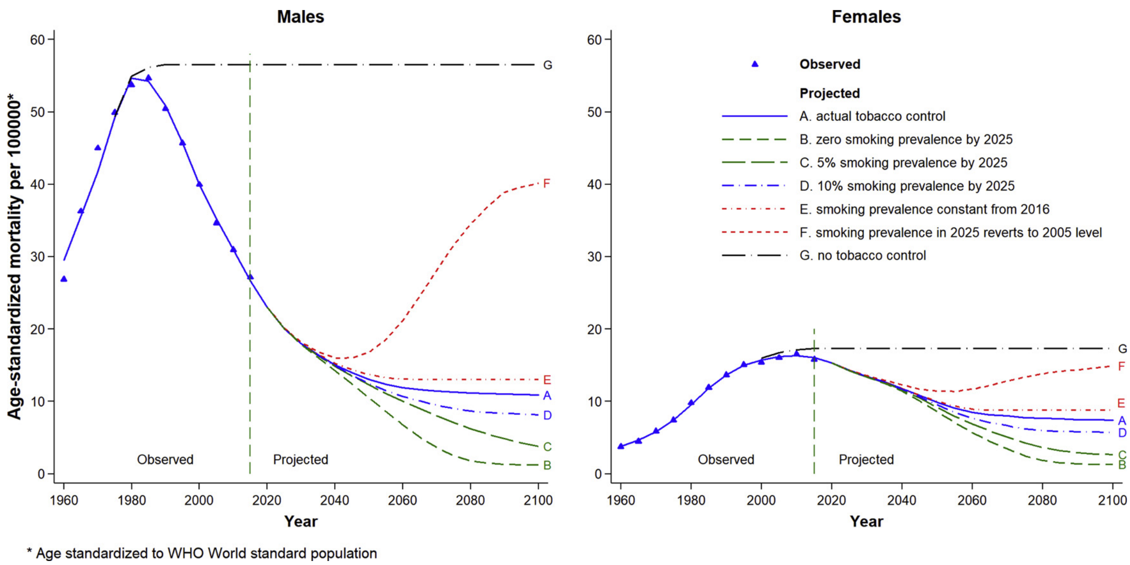


Fig. 2. Australian lung cancer mortality rates as observed and projected under different tobacco control scenarios.

linear extrapolation based on the trend of birth cohort effects between 1960 and 1990.

2.3. Number of deaths from lung cancer

To estimate the number of deaths from lung cancer, the predicted sex-age-period-specific lung cancer mortality rates were applied to the population sizes projected by the ABS [11,12]. The main results are based on the ABS series B (medium population growth), while results based on series A (low population growth) and series C (high population growth) are also reported to indicate the possible variation in mortality estimates due to potential changes in future population sizes. All statistical analyses were performed using STATA (version 13.1, STATA Corporation, College Station, TX).

3. Results

The observed and projected age-standardized lung cancer mortality rates for each tobacco control scenario are presented in Fig. 2. In the 'no tobacco control' scenario, a counterfactual scenario with no tobacco control initiatives ever implemented, cigarette consumption, smoking prevalence and lung cancer mortality rates for both males and females would remain at their highest historical levels. In the 'actual tobacco control' scenario, the decreasing trend in the male mortality rate would continue into the future, and the female mortality rate would continue the decline that started in 2011-2015. For both males and females these declines in the mortality rates are expected to level off after 2060. By comparison, for scenarios with 10%, 5% or 0% smoking prevalence by 2025, the lung cancer mortality rates would decline faster after 2040. In the 'zero smoking by 2025' scenario, the overall lung cancer mortality rates would reach the lowest possible level by around 2090 (1.3 per 100,000 for both males and females).

The annual number of lung cancer deaths and number of deaths averted due to actual tobacco control interventions are presented in Fig. 3. If no tobacco control initiatives had been implemented, there would have been an estimated 392,116 lung cancer deaths in the period 1956–2015. We estimate that during this time period there were 78,925 deaths (75,839 males and 3,086 females) averted due to tobacco control interventions, with those impacting deaths over this period implemented before 1990. This is equivalent to 20.1% of the estimated total number of possible lung cancer deaths for the 'no tobacco control' scenario. Projecting into the future, we estimate that 1.9 million deaths (1,579,515 males and 320,856 females) will be averted over the period 2016–2100 due to the tobacco control interventions implemented up to 2016. This is equivalent to 67.3% of the estimated total number of possible lung cancer deaths (2,824,405 deaths; 2,077,816 males and 746,589 females) under the 'no tobacco control' scenario (Table 1). Therefore, considering both past and future deaths together, almost 2 million of 3.2 million potential deaths from lung cancer have been prevented.

The potential impact of different future tobacco control scenarios on future lung cancer mortality is presented in Fig. 4 and Table 1. Compared to the 'actual tobacco control' scenario, if Australia can achieve 10%, 5% or 0% smoking prevalence by 2025 a further 3.4%, 7.4% and 12.8% of lung cancer deaths could be averted (55,028, 108,561, 212,603 additional deaths averted for males, and 42,404, 100,153, 147,954 additional deaths averted for females, respectively). By contrast, if the smoking prevalence remains constant at 2016 levels into the future instead of continuing to decline due to existing tobacco control initiatives, we estimate that there would be 73,883 additional deaths (45,904 males and 27,979 females) compared to the 'actual tobacco control' scenario. Finally, in the scenario where the prevalence in 2025 has reverted to 2005 levels, 653,957 additional deaths (498,615 males and 155,342 females) could occur compared to the 'actual tobacco control' scenario. The variation in mortality estimates due to potential changes in future population sizes are presented in Appendix 4.

4. Discussion

The successful implementation of a range of tobacco control interventions has been crucial to the decline in smoking prevalence and cigarette consumption evident in many developed countries, including Australia, and tobacco control measures have demonstrably resulted in significant reductions in lung cancer mortality [4,5,23]. A decrease in the prevalence of smoking amongst Australian men began in the 1950s, likely due to increasing awareness of research into the link between smoking and cancer that was published in the 1940 s–1950 s [9,28]. This early research contributed to the now solid evidence-base linking smoking and lung cancer, and initiated tobacco control interventions internationally. Various tobacco control initiatives began to be introduced in Western countries from the 1950s onwards [5,23,25], including early bans on cigarette advertisements in the USA and UK in the 1960s [25]. In Australia, health warnings were first mandated on all cigarette packs in 1973 and all cigarette advertising on radio and television was banned in 1976 [24]. More recent tobacco control interventions in Australia include media campaigns, plain packaging, and an

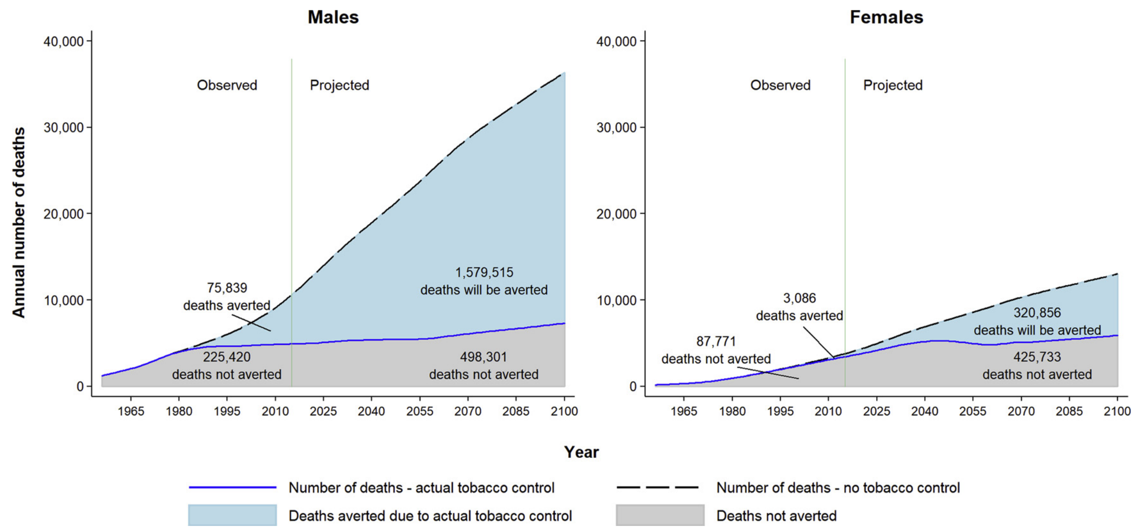


Fig. 3. Annual number of lung cancer deaths and estimated numbers of deaths averted due to actual tobacco control over the period 1956–2100 in Australia.

Table 1
Numbers of deaths averted due to tobacco control in Australia: estimated for 1956–2015 and projected for 2016–2100.

	Males		Females		Overall	
	n[a]	%[b] of D_G	n[a]	%[b] of D_G	n[a]	%[b] of D_G
Estimated number of deaths in 1956-2015						
Number of deaths assuming no tobacco control (D_G)	301,259		90,857		392,116	
Number of actual deaths (D_A)	225,420	74.8	87,771	96.6	313,191	79.9
Number of deaths averted due to current tobacco control (D_G-D_A)	75,839	25.2	3,086	3.4	78,925	20.1
Projections for 2016-2100						
Number of deaths assuming no tobacco control (D_G)	2,077,816		746,589		2,824,405	
Actual tobacco control						
Number of deaths (D_A)	498,301	24.0	425,733	57.0	924,034	32.7
Number of deaths will continue to be averted (D_G-D_A)	1,579,515	76.0	320,856	43.0	1,900,371	67.3
Zero smoking prevalence by 2025						
Number of deaths (D_B)	285,698	13.7	277,779	37.2	563,477	20.0
Number of deaths will continue to be averted (D_G-D_B)	1,792,118	86.3	468,810	62.8	2,260,928	80.0
Additional number of deaths averted[c] (D_A-D_B)	212,603	10.2	147,954	19.8	360,557	12.8
5% smoking prevalence in 2025						
Number of deaths (D_C)	389,740	18.8	325,580	43.6	715,320	25.3
Number of deaths will continue to be averted (D_G-D_C)	1,688,076	81.2	421,009	56.4	2,109,085	74.7
Additional number of deaths averted[c] (D_A-D_C)	108,561	5.2	100,153	13.4	208,714	7.4
10% smoking prevalence in 2025						
Number of deaths (D_D)	443,273	21.3	383,328	51.3	826,602	29.3
Number of deaths will continue to be averted (D_G-D_D)	1,634,543	78.7	363,261	48.7	1,997,803	70.7
Additional number of deaths averted[c] (D_A-D_D)	55,028	2.6	42,404	5.7	97,432	3.4
Smoking prevalence constant from 2016						
Number of deaths (D_E)	544,205	26.2	453,711	60.8	997,917	35.3
Number of deaths will continue to be averted (D_G-D_E)	1,533,611	73.8	292,878	39.2	1,826,488	64.7
Additional number of deaths averted[c] (D_A-D_E)	−45,904	−2.2	−27,979	−3.7	−73,883	−2.6
Smoking prevalence reverts to 2005 levels						
Number of deaths (D_F)	996,916	48.0	581,074	77.8	1,577,990	55.9
Number of deaths will continue to be averted (D_G-D_F)	1,080,900	52.0	165,515	22.2	1,246,415	44.1
Additional number of deaths averted[c] (D_A-D_F)	−498,615	−24.0	−155,342	−20.8	−653,957	−23.2

[a] Number of deaths estimated based on the ABS series B (medium population growth).
[b] % over total number of deaths assuming no tobacco control (D_G) within the time period.
[c] Compared to the number of deaths averted in the actual tobacco control scenario.

annual 12.5% increase in tobacco excise implemented from 2013 to 2020 [24]. Our study has, for the first time, provided a quantitative evaluation of the impact of changes in smoking behaviour on lung cancer mortality in Australia, largely as the result of these tobacco control measures. Compared to a counterfactual scenario in which tobacco control was never implemented, we estimate that tobacco control interventions in Australia have already averted 20% of the possible lung cancer deaths in the period 1956–2015, and should in future avert around two-thirds of lung cancer deaths that would have been expected by the end of the century – a total of 2 million lives saved overall.

Continuing commitment and efforts to reduce smoking prevalence remain a significant public health priority, because the positive effects of the existing tobacco control measures taken to date are expected to lessen over time. Without further action, the decline in lung cancer

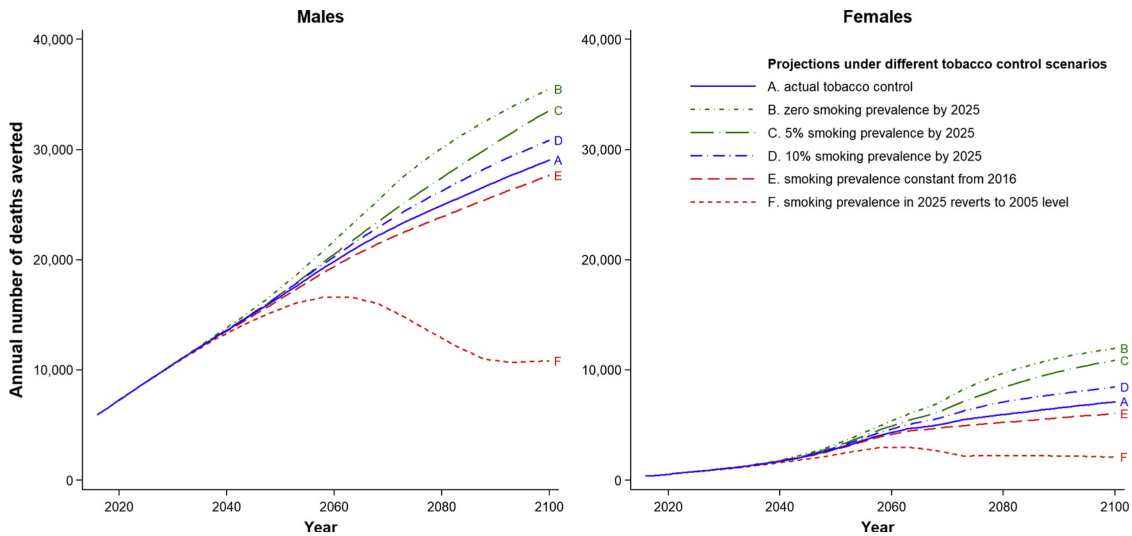


Fig. 4. Estimated numbers of lung cancer deaths that could be averted under different tobacco control scenarios over the period 2016–2100 in Australia.

mortality rates due to tobacco control initiatives is expected to level off in the 2060s for both males and females. There remains the potential to save several hundred thousand more lives over the course of the century if Australia could achieve a lower smoking prevalence by 2025. Although achieving a target prevalence of 5% or less by 2025 appears ambitious, we modelled the impact in order to quantify the gains possible if such a 'stretch goal' could be achieved, and there are precedents for such targets in other countries, such as New Zealand's 'Smoke-free 2025' [29]. We have also shown that even with a less ambitious target substantial further gains could still be realized – with ˜100,000 more lives saved from lung cancer – if a sustained reduction of smoking prevalence to 10% or less could be achieved by 2025. As tobacco smoking is still one of the largest preventable causes of death and disease in Australia [30], the wider benefits from tobacco control on all smoking-related deaths would be even greater.

There have been recent concerns regarding a potential risk of reversing trends in the smoking rate due to the promotion of tobacco products on the internet [23,31,32], and a potential adverse impact of electronic cigarettes (e-cigarettes) on smoking initiation rates [33,34]. Recent studies have shown that the use of e-cigarettes may be a precursor to initiating tobacco smoking by young people [33–35]. Australian national data indicate that lifetime use of e-cigarettes significantly increased across all age groups under 65 years between 2013 and 2016, and this increase was particularly marked in younger people [36]. This indicates that e-cigarettes have high appeal to young people and a potential reversing trend in smoking prevalence driven by the promotion of e-cigarettes is of major concern. A recent study in the US has demonstrated the extraordinary growth in the use of a specific type of e-cigarette by youth and young adults as a result of a variety of new media marketing [37]. There are concerns about the potential for e-cigarette usage to be a gateway to tobacco smoking; this is pertinent since our study has shown that any increase in the rate of smoking would result in a substantial adverse impact on lung cancer mortality rates.

Our study has estimated population-level effects, however, data have shown considerable differences in smoking behaviour across sociodemographic groups in Australia. Substantially higher smoking rates have been observed for those of lower socioeconomic status or with less education [36,38,39]; lesbian, gay and bisexual Australians; individuals with a mental illness; some migrant communities [40–43]; and Aboriginal and Torres Strait Islander Australians [44]. Consequently, these high-risk groups are at greater risk of smoking-related harm. For example, despite the fact that smoking rates amongst Aboriginal and Torres Strait Islander Australians are falling [45], they are still almost three times more likely to smoke as non-Indigenous Australians [44], and experience a mortality rate from lung cancer that is 2.1 times higher than the rate of non-indigenous Australians [46], with tobacco use being the biggest contributor to this [30].

Given all these challenges towards eliminating smoking, this study highlighted the urgent need for more effective and targeted tobacco control strategies to be implemented. Research has shown that the tobacco control strategies previously implemented in Australia, including increased tobacco taxation, more comprehensive smoke-free laws and increased mass media campaigns, have successfully contributed to the decrease in the smoking rate [3,4]. Implementing evidence-based approaches that target marginalized groups, such as social media campaigns and cessation support services for Aboriginal and Torres Strait Islander people or low socioeconomic status groups, could be a beneficial complement to population-level tobacco control efforts.

While our results demonstrate the potential for significant positive outcomes from reductions in smoking prevalence, because the risk of lung cancer remains elevated for many years after smoking cessation [47], even in the best-case scenarios, we have estimated that it will take until the 2090s for overall population lung cancer mortality rates to reach those seen in non-smokers. In addition, in spite of falling prevalence we still estimate that there will be over 2 million smokers in Australia in 2025, which will continue to result in significant lung cancer mortality rates. Thus, to further reduce lung cancer mortality in the shorter term there is a need for improvements in the diagnosis and treatment of lung cancer, such as building on recent advances in risk-targeted lung cancer screening [48], and targeted therapy for lung cancer [49–51].

As with all modelling studies, there are some limitations and uncertainties inherent in the inputs and assumptions used in our analyses, and thus the results of this study should be interpreted with some care. Firstly, we did not explicitly model the impact of exposure to second-hand smoke, although implicitly this has to some extent been taken into account via the modelling of overall cohort exposure effects. Secondly, the model did not include possible changes in other factors that can contribute to lung cancer mortality, including environmental and occupational exposures, and cancer screening or treatment patterns [9]. The projection models also assumed that the association between age and lung cancer risk remained constant over time [8,20]. Thirdly, our estimate of the number of lung cancer deaths averted due to tobacco control initiatives depends on the counterfactual estimates of the magnitude of smoking exposure in the absence of any tobacco control. These estimates were based on the highest historical levels of smoking exposure, which may be an underestimate of the highest rates that might have been experienced in the complete absence of tobacco control throughout history. This underestimation is particularly possible for females, as it is likely that the smoking rate for females may have increased substantially in the absence of tobacco control measures. Fourthly, in future scenarios with a specific smoking prevalence achieved by 2025, the estimated corresponding tobacco consumption level and the estimates of future cohort effects were based on current smoking prevalence trends, and there is always uncertainty when extrapolating current trends into the future. Nonetheless, despite these issues our study has many strengths. Our model incorporated detailed historical smoking prevalence and intensity data, which are the most significant determinants of lung cancer death, and the model was previously validated using 25 years of observed data [9]. Also, the projections were based on long term observed lung cancer mortality data with high data quality and population coverage [10]; these data are very complete and have been validated [52].

In summary, our estimates of the number of deaths which could be averted by different tobacco control scenarios illustrate how tobacco control may impact future lung cancer mortality rates in Australia. Tobacco control policies implemented in Australia have resulted in a significant reduction in lung cancer mortality and are expected to yield ongoing benefits over the next several decades. Unfortunately, however, lung cancer will continue to be a significant public health concern in Australia, and vigorous efforts towards zero smoking prevalence are critical and urgent to further reduce the impact of lung cancer in the Australian population.

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Conflicts of interest statement

KC is co-PI of an unrelated investigator-initiated trial of cytology and primary HPV screening in Australia ('Compass'), which is conducted and funded by the Victorian Cytology Service (VCS), a government-funded health promotion charity. The VCS have received equipment and a funding contribution for the Compass trial from Roche Molecular Systems and Ventana Inc USA. However, neither KC nor her institution (Cancer Council NSW) receives direct funding from industry for this trial or any other project.

Ethics approval and consent to participate

Not applicable.

Authorship contribution statement

KC: conceived the study. QL: designed the study, conducted statistical analysis and interpretation, visualization, and drafted the manuscript. JS, DO'C and KC: contributed to the study design, interpretation of results and drafting of the manuscript. XQY, MC, SW, FP and PS: contributed to the statistical analysis. PG, AD, BF, SD, TB and EB: contributed to the interpretation of results and provided advice on policy aspects. All authors critically revised the manuscript. All authors read and approved the final manuscript.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.lungcan.2019.02.028.

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