Estimating smoking prevalence and attributable disease burden in 195 countries and territories, 1990-2015: a systematic analysis from the Global Burden of Disease Study 2015.

GBD 2015 Tobacco Collaborators

Summary

Background

The scale-up of tobacco control, especially following the adoption of the Framework Convention for Tobacco Control, is a major public health success story. Nonetheless, smoking remains a leading risk for early death and disability globally, and therefore continues to require sustained political commitment. The Global Burden of Diseases, Injuries, and Risk Factors study (GBD) offers a robust platform through which global, regional, and national progress toward achieving smoking-related targets can be assessed.

Methods

We synthesised 2,818 data sources with spatiotemporal Gaussian process regression and produced estimates of daily smoking prevalence by sex, age group, and year for 195 countries and territories from 1990 to 2015. We analysed 38 risk-outcome pairs to generate estimates of smoking-attributable mortality and disease burden, as measured by disability-adjusted life years (DALYs). We then performed a cohort analysis of smoking prevalence by birth-year cohort to better understand temporal age patterns in smoking. Last, we conducted a decomposition analysis, wherein we parsed out changes in all-cause smoking-attributable DALYs due to changes in population growth, population ageing, smoking prevalence, and risk-deleted DALY rates. Finally, we explored results by level of development using the Socio-demographic Index (SDI).

Results

Globally, the age-standardised prevalence of daily smoking was 25.0% (95% uncertainty interval 24.2–25.7%) for men and 5.4% (5.1–5.7%) for women, representing 28.4% (25.8-31.1%) and 34.4% (29.4–38.6%) reductions, respectively, since 1990. A greater percentage of countries and territories achieved significant annualised rates of decline in smoking prevalence from 1990 to 2005 than from 2005 to 2015; however, only two countries saw significant annualised increases in smoking prevalence between 2005 to 2015 (Congo for men and Kuwait for women). In 2015, 11.5% of global deaths (6.4 million, [5.7–7.0 million]) were attributable to smoking worldwide, of which 52.2% took place in four countries (China, India, USA, and Russia). Smoking was ranked among the five leading risk factors by DALYs in 109 countries and territories in 2015, rising from 88 geographies in 1990. In terms of birth cohorts, male smoking prevalence followed similar age patterns across levels of SDI, whereas much more heterogeneity was found in age patterns for female smokers by level of development. While smoking prevalence and risk-deleted DALY rates mostly decreased by sex and SDI quintile, population growth, population aging – or a combination of both – drove rises in overall smoking-attributable DALYs among low to middle SDI geographies between 2005 and 2015.

Interpretation
The pace of progress in reducing smoking prevalence has been heterogeneous across geographies, development status, and sex – and as highlighted by more recent trends, maintaining past rates of decline should not be taken for granted, particularly among women and in low to middle SDI countries. Beyond the influence of the tobacco industry and societal mores, a critical challenge facing tobacco control initiatives is that demographic forces are poised to heighten smoking's global toll, unless progress in preventing initiation and promoting cessation can be substantially accelerated. Greater success in tobacco control is possible but requires effective, comprehensive, and adequately implemented and enforced policies, which may in turn require global and national levels of political commitment beyond what has been achieved during the past 25 years.

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Research in Context

Evidence before this study

Smoking is a widely-recognised risk factor for premature morbidity and mortality, but adequate monitoring of smoking levels and trends throughout the world has been challenging. Increasing investments in multi-country survey series has improved the availability of data on smoking behaviours, particularly among lower income countries, but such surveys are relatively infrequent and differences in survey questions and definitions can hinder appropriate comparisons between countries and across time. Through the Global Burden of Diseases, Injuries, and Risk Factors study in 2013 (GBD 2013), researchers collated a wide array of data sources and sythesised them to produce comprehensive, comparable estimates of daily smoking prevalence, by sex and age group, for 188 countries from 1990 to 2013. Additional analyses, including those by Bilano and colleagues in 2015, have applied similar methods to project trends in tobacco use through 2025 in 173 countries for men and 178 countries for women.

Added value of this study

With the 2015 update to the GBD, the number of data sources included was substantially increased and the estimation process for both smoking prevalence and attributable disease burden, as measured by disability-adjusted life-years (DALYs), has been improved. Two novel analyses are also provided through the GBD 2015 study: a birth cohort analysis of smoking patterns over time and a decomposition analysis to parse out changes in total DALYs attributable to smoking to changes in population growth, population ageing, smoking prevalence, and risk-deleted DALY rates. The latter assessment can assist with identifying which factors are contributing to changes in disease burden due to smoking – demographic trends, efforts to address smoking, or some combination of these factors. Further, we used the Socio-demographic Index (SDI), a new summary measure of overall development from GBD 2015, to examine levels and trends in smoking prevalence and attributable burden across the development spectrum.

Implications of all the available evidence

Amid gains in tobacco control worldwide, smoking remains a leading risk factor for early death and disability. While there have been some success stories, for many countries and territories, faster annualised rates of decline in smoking prevalence occurred from 1990 to 2005 compared to 2005 to 2015. Although smoking prevalence and risk-deleted DALY rates fell across SDI quintiles, population growth and aging ultimately offset these gains and contributed to overall increases in smoking-attributable disease burden in low to middle SDI geographies. Intensified tobacco control and strengthened monitoring are required to further reduce smoking prevalence and attributable burden, particularly given that such demographic factors like population ageing are not easily amenable to intervention.

Introduction

The toll of tobacco on population health is immense. Smoking remained the second-leading risk factor for early death and disability globally in 2015. Smoking has claimed more than five million lives each year since 1990,[1] and its contribution to overall disease burden is growing, especially among lower income countries. The negative effects of smoking extend well beyond individual and population health,[2] as billions of dollars in lost productivity and healthcare expenditure are related to smoking every year.[3] Successfully combatting the tobacco industry's pursuit of new smokers has been further complicated by the substantive – and sometimes rapid – social, demographic, and economic shifts occurring worldwide.[4–6] As the tobacco industry moves to target previously untapped markets, including women, youth, and people living in low- and middle-income countries,[6,7] strong tobacco control policies and timely monitoring of smoking patterns is imperative.

The last decade has brought a significant expansion and strengthening of tobacco control initiatives, harnessing a wide range of effective interventions and policy instruments for addressing the tobacco epidemic. Successful strategies include taxation of tobacco products,[9] bans on smoking in public places and instituting smoke-free zones,[10,11] restrictions on the marketing and promotion of cigarettes, including plain packaging laws,[12] community- and nation-wide smoking cessation interventions,[13,14] and enforcement of both text and pictorial warning labels on tobacco products.[15,16] Efforts to implement comprehensive tobacco control policies culminated in the adoption of the World Health Organization's (WHO) Framework Convention on Tobacco Control (FCTC) in 2003.[17] The FCTC, the world's first public health treaty, is viewed as a key driver of recent progress in reducing tobacco consumption and smoking prevalence in many regions of the world.[18] As of 2016, 180 parties have ratified the FCTC,[19] and many use WHO's MPOWER measures,[20] established in 2008, to guide national and local FCTC compliance.[21] More recently, WHO introduced the 25x25 Non-communicable Disease (NCD) targets, which include decreasing tobacco use by 30% between 2010 and 2025.[22] A number of countries have committed to even stronger anti-smoking goal, setting national targets to become tobacco-free.[23] Additionally, strengthening FCTC implementation was explicitly included in the United Nations' Sustainable Development Goals (SDGs), using age-standardised smoking prevalence as an indicator to track progress.[24] With tobacco control's increasing prioritisation on the global stage, accurately monitoring patterns in smoking and associated health outcomes is critical for identifying optimal intervention strategies across geographies, demographic groups, and the development spectrum.

Previous analyses of smoking prevalence and attributable disease burden often were hindered by poor data availability, methodological limitations, or both.[25–27] Investments in survey series focused on tobacco, such as the Global Adult Tobacco Surveys (GATS) and the Global Youth Tobacco Surveys (GYTS), have supported more in-depth assessments of national tobacco use.[28] Nonetheless, remaining data gaps across countries and time, as well as differences in smoking-related questions and definitions among available data sources, necessitated considerable analytic improvements to produce a systematic and consistent understanding of smoking patterns. As part of the Global Burden of Diseases, Injuries, and Risk Factors study for 2013 (GBD 2013), Ng and colleagues generated the first comprehensive, comparable estimates of smoking prevalence and tobacco consumption for 188 countries from 1980 to

2013[29] Since then, other studies have used similar data synthesis approaches to project smoking trends from 2010 to 2025 in 173 countries for men and 178 countries for women.[30] Previous GBD studies[31,32] have evaluated the contribution of smoking to overall disease burden through the comparative risk assessment (CRA) framework developed by Murray and Lopez.[33] Recent studies have quantified the global effects of tobacco on achieving NCD mortality targets[34] and life expectancy,[35] while several examined smoking-attributable mortality and nonfatal health outcomes for specific locations.[36,37] Yet few tobacco research endeavours can draw from the same breadth of data sources, analytic rigor in data synthesis, and independent, international collaboration as supported by the GBD.

In this analysis, we used the GBD 2015 study to assess smoking prevalence and smoking-attributable disease burden, based on deaths and disability-adjusted life-years (DALYs), by sex and age group for 195 countries and territories from 1990 to 2015. Since GBD 2013, we substantially improved both the quantity of data informing our estimation process as well as the modelling strategies used to calculate smoking prevalence and attributable burden. For the first time, we investigate differences in smoking prevalence and attributable burden alongside indices of overall development, as measured by the Socio-demographic Index (SDI), a summary measure of income per capita, educational attainment, and total fertility rate (TFR).[38] Additionally, we assess age and sex patterns by birth cohort across levels of development. Finally, we conduct a decomposition analysis of potential drivers of smoking-attributable disease burden over time, seeking to parse out changes due to smoking exposure from those due to other demographic factors, such as population growth and aging.

Methods

This study follows the overall GBD 2015 CRA framework, details of which have been previously published.[1] Here we summarise the main steps in the estimation process and provide more detail on data inputs and modelling strategies in the appendix pp 5-9. This study fully adheres to the Guidelines for Accurate and Transparent Health Estimates Reporting (GATHER).[39]

Estimating smoking exposure

We calculated two exposure measures in this study: prevalence of daily smoking of tobacco and the smoking impact ratio; detailed descriptions of these methods have been published previously.[29] We defined a daily smoker as an individual using any type of smoked tobacco product, including both manufactured and hand-rolled cigarettes, hookah, cigars, pipes, and bidis, among others, on a daily basis. We focused on daily smoking, as opposed to current smoking, because the majority of data sources measure it directly and also because there are more significant health effects associated with daily smoking.[40,41] To estimate daily smoking prevalence we used 2,818 data sources, covering 2,928 geography-years of data, identified through the Global Health Data Exchange (GHDx), WHO InfoBase Database, and International Smoking Statistics Database. At least one data source was available for 191 out of 195 countries and territories, and 140 locations had at least five data sources. Countries lacking data were Central African Republic, Angola, Somalia, and South Sudan; additional details on data sources are found in the appendix pp 5-6. For any data that did not match our exposure definition (daily smoking of any tobacco product), we adjusted for frequency of use or type of tobacco consumed to avoid potential biases. Improving upon methods used by Ng and colleagues,[29] we adjusted for smoking frequency and type simultaneously, which allowed us to account for their mutual correlations with each other (appendix pp 7-8). Secondhand smoke exposure is estimated separately in GBD and is not included in this analysis.

We generated estimates of smoking prevalence by sex and five-year age groups starting at age 10. Any data that spanned multiple age groups or were reported for both sexes combined were split based on the age-sex patterns observed from data sources with multiple age-sex groupings; this process was based on the approach used by Ng and colleagues.[29] We then used spatiotemporal Gaussian process regression (ST-GPR), a data synthesis method widely used in GBD,[1] to model smoking prevalence. ST-GPR allowed us to draw strength across multiple dimensions (geography, time, and age), incorporate both data and model uncertainty, and produce a full time-series of estimates for all 195 geographies in this analysis. In brief, the mean function used in GPR was a combination of a hierarchical linear mixed-effects model using supply-side tobacco availability as a covariate plus residuals smoothed across geography, time, and age. Full details on the modeling strategy, including the data sources and estimation process used for the supply-side tobacco availability covariate, are provided in the appendix pp 5-9.

The second exposure measure, the smoking impact ratio, was first described by Peto and Lopez[42] as part of a method to estimate smoking-attributable burden in the absence of information on smoking patterns. The smoking impact ratio is defined as the population lung cancer mortality rate in excess of the background lung cancer mortality rate observed among non-smokers in the population, relative to the excess lung cancer mortality rate observed in a reference group of smokers. We computed the smoking impact ratio for each analytic unit using the geography-, year-, age-, and sex-specific population lung cancer mortality rates from GBD 2015,[43] and reference group lung cancer mortality rates from prospective cohort studies (appendix p 9).

Defining risk-outcome pairs

We assessed all available evidence that supported causal relationships between smoking and 38 health outcomes using a systematic approach adapted from Hill's criteria for causation[44] and the World Cancer Research Fund evidence grading schema (appendix p 9).[45] For GBD 2015, we added seven new outcomes to those identified in GBD 2013:[31] larynx cancer, peptic ulcer disease, rheumatoid arthritis, cataract, macular degeneration, hip fracture, and non-hip fracture.

Estimating attributable burden

We used five-year lagged smoking prevalence in estimating smoking attributable burden for cardiovascular diseases, tuberculosis, diabetes, lower respiratory infections, asthma, cataracts, macular degeneration, fractures, rheumatoid arthritis, and peptic ulcer disease. We chose a five-year lag based on literature showing that most risk-reduction occurs within five years of quitting smoking.[46] We used the smoking impact ratio in estimating smoking attributable burden for cancers, chronic obstructive pulmonary disease (COPD), interstitial lung disease, other chronic respiratory diseases, and pneumoconiosis. A complete list of outcomes and their associated exposure metric is available in the appendix pp 31-32.

For each outcome included in this analysis we used relative risk (RR) estimates derived from prospective cohort studies comparing smokers to never smokers (appendix p 9). Population attributable fractions (PAFs) were calculated based on estimates of exposure, RRs, and the theoretical minimum risk exposure level (TMREL) for smoking (zero smoking). Following PAF calculation, we multiplied estimates of deaths and DALYs by outcome-specific PAFs, and then summed them across all 38 outcomes to compute overall disease burden attributable to smoking. The appendix provides more detail on the process for computing smoking attributable burden (p 9).

Uncertainty analysis

We captured and propagated uncertainty through all steps of the analysis, including sampling uncertainty from data extraction, uncertainty from models used to adjust data reported in non-standard frequency-type combinations, uncertainty in the ST-GPR model, and uncertainty in deaths and DALYs for the 38 included outcomes. Ultimately, we produced 1,000 draws of exposure and attributable burden estimates, for each geography, year, age, and sex, from which 95% uncertainty intervals (UIs) were taken using the 2.5 percentile and 97.5 percentile of the distribution.

Decomposing changes in deaths and DALYs

To parse out the drivers of changes in smoking attributable DALYs from 2005 to 2015, we assessed the relative contribution of four factors: (1) population growth, (2) population age structure, (3) risk-deleted DALY rates, and 4) smoking exposure. Risk-deleted rates are defined as the DALY rates that would have been observed if we removed smoking as a risk factor. We estimated risk-deleted DALY rates by multiplying the observed cause-specific DALY rates by one minus the cause-specific PAFs. For the decomposition analysis, we used the methods developed by Das Gupta;[47] see the appendix p 10 for more detail.

Smoking and its relationship to SDI

We present results aggregated by level of SDI, a composite indicator of development estimated for each geography based on lag-distributed income per capita, average educational attainment among individuals over age 15 years, and TFR in 2015. SDI values were scaled to a range from 0 to 1, with 0 representing the lowest educational attainment, lowest income, and highest TFR observed in any geography between 1980 and 2015, and 1 equaling the highest educational attainment, highest income, and lowest TFR during this time. Further details on SDI computation are available elsewhere, [43] and SDI values for each geography are included in the appendix pp 21-25.

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Global, regional, and national levels and trends of daily smoking

Globally, the age-standardised prevalence of daily smoking was 25.0% (95% uncertainty interval 24.2–25.7%) in men and 5.4% (5.1–5.7%) in women, in 2015 (Table 1). Fifty-one countries and territories had significantly higher prevalence of smoking than the global average for men, and these countries were primarily located in Central and Eastern Europe and Southeast Asia **(Figure 1)**. For women, 70 countries, mainly in Western and Central Europe, significantly exceeded the global average. Among men, prevalence of daily smoking was highest in middle SDI countries, whereas for women high SDI countries had the highest prevalence of daily smokers (Figure 2). Compared to other SDI levels, low SDI geographies generally had the lowest prevalence of daily smoking for both sexes. In 2015, Kiribati (47.8% [43.8–51.5%]), Indonesia (46.7% [43.9–49.5%]), and Laos (46.5% [42.6–50.3%]) recorded the highest levels of smoking among men, while Greenland (44.3% [41.1–47.6%]), Bulgaria (28.3% [24.5–32.0%]), and Greece (27.2% [24.6–29.6%]) registered the highest levels of smoking among women.

Between 1990 to 2015, the global age-standardised prevalence of daily smoking fell significantly for each sex, decreasing by 28.4% (25.8-31.1%) for men and 34.4% (29.4-38.5%) for women (Table 1). Fourteen countries (Algeria, Australia, Brazil, China, Democratic Republic of the Congo, Dominica, Iceland, Kenya, the Netherlands, New Zealand, Norway, Sweden, Switzerland, and the USA), eight of which are high SDI countries, recorded statistically significant annualised rates of decline 1990-2005 and 2005-2015, indicating sustained progress in tobacco control. Eighteen countries showed a faster annualised rate of reduction in daily smoking in the most recent decade compared to 1990-2005. The annualised rate of change for men increased significantly in six countries (Chile, Cyprus, Guyana, Romania, Saudi Arabia, and Serbia) between 1990 and 2005, but only one country (Congo) from 2005 to 2015. For women, the annualised rate of change increased significantly for six countries (Chile, Greece, Indonesia, Japan, Portugal, and South Korea) between 1990 and 2005 compared to one country (Kuwait) from 2005 and 2015. Focusing on the most recent decade, since 2005, 27.2% (*n*=53) of countries and territories recorded statistically significant decreases in age-standardised prevalence of male daily smoking, whereas only 16.4% (*n*=32) saw statistically significant reductions for women.

A focus on countries with large smoking populations

In 2015, there were 933.1 million (831.3–1,054.3 million) daily smokers in the world, 82.3% of whom were men (768.1 million [690.1–852.2 million]). The ten countries with the largest number of smokers together accounted for 63.6% of the world's daily smokers. China, India, and Indonesia – the three leading countries in total number of male smokers – accounted for 51.4% of the world's male smokers in 2015. On the other hand, USA, China, and India, which were the leading three countries in total number of female smokers, only accounted for only 27.3% of the world's female smokers. Together, these results suggest that the tobacco epidemic is less geographically concentrated for women than for men. In 2015, 33.1% of male smokers and 8.7% of female smokers lived in China alone, amounting to 253.9 million (241.2–266.6 million) and 14.4 million (10.5–19.5 million) daily smokers, respectively (Table 2).

Among the ten countries with the largest number of total smokers in 2015, seven recorded statistically significant declines in male smoking prevalence and five experienced statistically significant declines in female smoking prevalence since 1990. Of these countries, Brazil recorded the largest overall reduction in prevalence for both male and female daily smoking, which dropped by 56.5% (51.9–61.1%) and 55.8% (48.7–61.9%), respectively, between 1990 and 2015. Indonesia, Bangladesh, and the Philippines did not experience significant declines in male prevalence of daily smoking since 1990, and the Philippines, Germany, and India had no significant declines in smoking among women. Each of the three countries with female age-standardised smoking prevalence less than 3.0% (China, India, and Bangladesh) succeeded in keeping smoking prevalence low among women. Notably, female prevalence of daily smoking significantly increased in Russia and Indonesia since 1990 (Table 2).

A focus on adolescents

Delving into the smoking patterns of adolescents can shed light on trends in smoking initiation. Most initiation of sustained smoking occurs between ages 15 and 19,[48] so in this section we are focusing on populations aged 15 to 19 years. Between 1990 and 2015, the global prevalence of daily smoking for this age group significantly decreased for each sex, falling from 16.1% (14.4–18.0%) to 10.6% (9.3–12.1%) for men and from 4.8% (4.3–5.6%) to 3.0% (2.6–3.7%) for women (Table 2). Despite global decreases, several countries still had a high prevalence of smoking among individuals aged 15-19 years. In 2015, there were 22 countries with female smoking prevalence in this age group above 15.0%, 18 of which were located in Western or Central Europe. Countries with high male smoking prevalence were much more dispersed. Of the 26 countries with male smoking prevalence above 20.0%, seven were in Eastern Europe, and the remainder were spread across 10 other regions (Supplemental Figure S2). The rank of countries with the largest smoking populations for the 15-19 age group was, for the most part, consistent with the rank for all-age smoking populations (Table 2). Among countries with the largest smoking populations, Germany had the highest smoking prevalence among young women (15.9%, [10.1–23.4%]), which did not significantly change between 1990 and 2015. Indonesia not only had one of the highest prevalence of daily smoking among men aged 15-19 years (27.7%, [18.4–38.3%]), but also the third largest smoking population in this age group and experienced no significant change in smoking prevalence among young adults between 1990 and 2015.

While no country exhibited a significant increase for men or women in this age group since 2005, only three countries saw smoking prevalence among 15-to-19 year-olds significantly drop for both men and women since 2005 (New Zealand, Iceland, and the USA). Iceland had the largest significant decline among men, decreasing from 14.8 (11.7–18.5%) in 2005 to 9.0 (5.6–13.3%) in 2015. New Zealand had the largest significant decline among women, dropping from 20.8 (18.1–23.8%) in 2005 to 12.5% (10.1–15.5%) in 2015.

Shifts in patterns of smoking across cohorts

Parsing out daily smoking prevalence by age group and birth cohort allows for a more fine-grained examination of smoking prevalence, age patterns, and temporal trends by level of development (Figure 2). Male age patterns of smoking were fairly consistent across levels of SDI, with prevalence generally peaking between the ages of 25 and 35 years. For women, however, age patterns varied more by SDI:

female smoking prevalence typically peaked around age 25 for high and high-middle SDI countries, while prevalence generally increased until the age of 60 in low to middle SDI countries. Across birth cohorts, smoking prevalence decreased by age group, sex, and SDI level. The most notable declines were observed in high and high-middle SDI countries for men, where sizeable reductions in smoking prevalence among 15 to 24 year-olds occurred across birth cohorts. Middle SDI countries, which have the highest levels of daily smoking among men, experienced minimal changes in prevalence across birth cohorts, suggesting far less progress in curbing smoking initiation or promoting cessation. For women, prevalence is consistently lower compared to men; nevertheless, reductions in smoking prevalence across birth cohorts generally were smaller than those observed for men. For both men and women, Latin America had notable success in reducing initiation and promoting earlier cessation, as evidenced by their marked reductions in prevalence in the 15-19 and 20-24 age groups along with an earlier age of peak prevalence and faster decline from peak prevalence in more recent birth cohorts (Supplemental Figure S4 in the appendix pp 17-18).

Deaths and disease burden attributable to smoking

In 2015, 6.4 million deaths (5.7–7.0 million) were attributable to smoking worldwide, representing a 4.7% (1.2-8.5%) increase in smoking-attributable deaths since 2005. Over 75% of these deaths were among men, and 52.2% took place in four countries (China, India, USA, and Russia) (Table 3). Smoking was the second-leading risk factor for attributable mortality among both sexes in both 2005 and 2015, following high-systolic blood pressure, which was the leading risk factor globally.[1] On the other hand, the relative ranking of smoking-attributable disease burden, as measured in DALYs, increased from third to second between 2005 and 2015. In 2015, there were 148.6 million (134.2–163.1 million) smoking-attributable DALYs globally, and smoking was the leading risk factor for attributable disease burden in 24 countries, an increase from 16 countries in 1990 (Figure 3). Further, smoking was ranked among the leading five risk factors for 109 countries in 2015. Between 2005 and 2015, only Egypt recorded a significant increase in the age-standardised smoking-attributable mortality rate among both sexes, increasing by 11.4% (0.3–24.7%) over that time period. On the other hand, 82 countries saw significant declines in their age-standardised smoking-attributable mortality rates since 2005.

Overall, in 2015, cardiovascular diseases (41.2%), cancers (27.6%), and chronic respiratory diseases (20.5%) were the three leading causes of smoking-attributable age-standardised DALYs for both sexes. Considering all risk factors, smoking was the leading risk factor for neoplasms and chronic respiratory diseases, but only the ninth leading risk factor for cardiovascular diseases.[1] The 30 leading causes of DALYs attributable to smoking, including changes over time, are shown in the appendix pp 19-20. For women, the leading cause of smoking-attributable DALYs was COPD, whereas the leading cause for men was ischaemic heart disease.

Decomposing changes in attributable burden due to smoking

Relative to changes in smoking exposure, the main drivers of overall changes in attributable burden due to smoking varied by both sex and SDI level (Figure 4). Since 2005, all-cause DALYs attributable to smoking for men decreased by 11.8% (10.0–13.9%) in high-SDI countries, the only SDI level with a significant decrease in attributable burden for men. For women, only middle-SDI countries experienced a significant reduction in all-cause DALYs attributable to smoking (a 22.6% decline [9.0–32.8%]) between 2005 and 2015. In both instances, a combination of declining smoking exposure and declining risk-deleted DALY rates contributed to overall reductions. Conversely, all-cause burden due to smoking significantly increased among low SDI and low-middle SDI countries since 2005 for men. This rise in attributable DALYs was primarily driven by a combination of population growth and population aging for both sexes. Among women, while rising exposure to smoking has resulted in increased DALYs due to smoking for low-middle SDI countries, this increase was not statistically significant. In general, population growth was the leading factor for increasing attributable burden due to smoking among the low SDI countries between 2005 and 2015. For countries of middle to high SDI, more pronounced sex differences emerged. For instance, declines in male smoking prevalence propelled an overall reduction in attributable burden for high SDI countries, whereas changes in smoking exposure had minimal effects on overall burden for women at similarly high levels of SDI.

A complete dataset of all results by geography, year, sex, and age group can be downloaded through the GHDx (http://ghdx.healthdata.org/), and an interactive data visualization of smoking prevalence results is available at http://vizhub.healthdata.org/tobacco/.

Discussion

Despite over half a century of unequivocal evidence of the harmful effects of tobacco on health,[49,50] in 2015, one out of every four men in the world was a daily smoker. Prevalence has been, and remains, significantly lower among women – approximately one in every 20 women smoked daily in 2015. Nonetheless, considerable progress has been accomplished over the past 25 years. Specifically, the age-standardised global prevalence of daily smoking fell to 15.3% (14.8-15.9%), a 29.4% (27.1-31.8%) reduction from 1990, with smoking rates declining from 34.9% (34.1-35.7%) to 25.0% (24.2-25.7%) among men and from 8.2% (7.9-8.6%) to 5.4% (5.1-5.7%) among women. These reductions were particularly pronounced in high SDI countries and Latin America, likely reflecting concerted efforts to implement strong tobacco control policies and programs in Brazil and Panama, among others.

Yet amid these gains, many countries with persistently high levels of daily smoking recorded marginal progress since 2005, and smoking remained among the leading risk factors for early death and disability in more than 100 countries in 2015, accounting for 11.6% of global deaths (10.4–12.8%) and 6.3% (5.6–7.1%) of global DALYs. Smoking patterns diverged by geography, level of development, sex, and birth cohort, emphasising the need for tailored approaches to change smoking behaviours. Although male smoking prevalence still far exceeded that of female smokers in 2015, the most pronounced reductions in smoking prevalence since 1990 were generally found for men – and more places saw minimal changes or increases in smoking among women. These trends highlight how the tobacco epidemic – and corresponding industry forces – has expanded beyond a male-centred health challenge.

Low to middle SDI countries saw increased disease burden attributable to smoking since 2005, a trend that that occurred despite variable declines smoking prevalence and risk-deleted DALY rates. Population growth or ageing – or a combination of both – ultimately contributed to increased disease burden attributable to smoking among these countries. In higher SDI countries, population growth and ageing offset the potential for larger gains in places where notable declines in smoking prevalence and risk-deleted DALY rates occurred. This finding points to a critical challenge ahead for tobacco control: unless progress in reducing current smoking and preventing initiation can be substantially accelerated, demographic forces – which are far less amenable to immediate intervention – are poised to heighten the disease burden associated with smoking's global toll.

Since 2005, the year when the FCTC was enforced, it has redefined global, regional, and national approaches to tobacco control and policy.[51,52] Case studies point to the successful uptake and enforcement of FCTC components in many countries with particularly prominent reductions in smoking prevalence. Pakistan, Panama, and India stand out as three countries that have implemented a large number of tobacco control policies over the past decade and have experienced remarkable declines in the prevalence of daily smoking since 2005, compared to declines observed between 1990 and 2005.[53–55] At the same time, many countries, including Australia, Brazil, Canada, South Korea, and USA, among others, achieved sizeable declines in smoking prevalence well before FCTC adoption.[56–61] Altogether, 25 countries recorded a faster annualised rate of decline from 1990 to 2005 than from 2005 to 2015.

Brazil which has achieved the third largest significant decline in age-standardised smoking prevalence since 1990, is one success story that can be referred to by other countries wishing to make significant gains in tobacco control. Brazil accomplished this reduction through a combination of tobacco control policies that began with advertising restrictions and smoking bans in some public places starting in 1996 and culminated with Brazil achieving the highest level of achievement in all MPOWER measures except for monitoring by 2011. Policies included strict warning label requirements, comprehensive public smoking bans, and a ban on all forms of direct and indirect advertisement. Additionally, Brazil promoted cessation programs, including national smoking quit lines and cost-covered nicotine replacement therapy and cessation counseling by physicians, while running regular anti-smoking mass-media campaigns. Also, Brazil complemented policies with fiscal interventions that included raising taxes and establishing minimum prices for tobacco products. Finally, Brazil has achieved high-levels of compliance with policies through enforcement.[62–66]

Critics of the FCTC argue that the treaty's effectiveness may be limited in various settings, especially since compliance has lagged in many countries of low-to-middle SDI.[67–69] A complex interplay of factors are involved in tobacco control, ranging from the differences in intensity of FCTC implementation and enforcement at local levels to shifts in sociocultural norms regarding smoking, particularly among women. For instance, marketing campaigns have long sought to reframe the female smoker as strong, independent, and socially desirable.[8,70] The FCTC, while necessary and vital for creating the policy environment for more effective tobacco control worldwide, is not sufficient to fully address each country's tobacco control needs. Rather, countries will need to both implement FCTC-stipulated measures and supplement such policies and programs with strong enforcement and high rates of compliance. For example, India, where 11.2% of the world's smokers live, supplemented the Cigarettes and Other Tobacco Products Act (COTPA) with the creation of a National Tobacco Control Programme (NTCP) in 2007. NTCP was created to strengthen implementation and enforcement of the various provisions of COTPA at the state and district level. It has been rolled out in phases and currently covers about 40% of all districts in India.[71]

Despite concerted efforts to control tobacco around the world, there remain a number of countries where current levels and recent trends raise concern about the potential impact of the tobacco epidemic on their population. For example, Indonesia, a country with very high levels of smoking, particularly among men and where 56.4% of men aged 20-24 years are daily smokers, has not yet ratified the FCTC and scores very poorly on the MPOWER indicators.[18] Also, in Russia prevalence among women has been increasing, and, until recently, there were very few laws related to tobacco control.[72] Russia passed a comprehensive tobacco control policy in 2014, and alongside effective implementation has the potential to achieve progress on tobacco control.[73] As a region, Eastern Europe has seen a statistically significant increase in smoking prevalence among women since 1990. Increases among women, along with a sustained high prevalence of male smokers, can be linked to tobacco industry targeting during the 1990s.[6] The tobacco industry is now turning its focus toward emerging markets in sub-Saharan Africa, seeking to exploit the continent's patchwork tobacco control regulations and limited resources to combat industry marketing advances.[74,75] Given the large effects of population growth and aging on smoking-attributable disease burden – and Africa's rapidly changing demographic profile – a renewed dedication to strong, proactive tobacco policies and monitoring will be vital for the continent.[76]

Understanding what works – and what does not – for tobacco control across contexts and within subpopulations (i.e., men and women, younger and older individuals, various socioeconomic groups) is of growing priority to donors, governments, and development partners alike. WHO assesses country achievements of MPOWER measures and publishes updated findings every two years.[18] Extending this important work of tracking tobacco control policy status and effectiveness in a more disaggregated, routine manner is a critical need, as evidenced by our study's heterogeneous trends in smoking prevalence by level of SDI, sex, and even birth cohort. For instance, little evidence and consensus exist on whether tobacco control policies and programs have differential effects for men and women, across levels of socioeconomic status,[77] or in different cultures.[78]

The 2030 agenda features tobacco control as a key component to sustainable development, with SDG Target 3.a calling for stronger FCTC implementation.[24] In many ways, the inclusion of tobacco control for the SDGs is a success, as the Millennium Development Goals (MDGs) were mainly focused on maternal and child health outcomes, specific areas of poverty reduction, and a subset of risk factors.[79] Reducing the prevalence of smoking (Indicator 3.a.1) may be an important avenue for country-level progress on the health-related SDGs, particularly given the strong linkages between smoking and NCD mortality (Indicator 3.4.1). In fact, several countries with the largest gains on the health-related SDG index between 2000 and 2015 recorded particularly sizeable reductions in age-standardised prevalence of smoking (e.g., Colombia and Iceland).[80] Nonetheless, the utility and potential impact of the SDGs on tobacco control may be hindered by the vagueness of Target 3.a ("Strengthen the implementation of the WHO FCTC in all countries, as appropriate") and absence of defined targets for reducing smoking prevalence by 2030. The 25x25 targets set by the WHO NCD Global Monitoring Framework,[22] while criticised for not being ambitious enough,[81] lay the foundation for more specific policy pursuits and greater accountability.

Ultimately, to move all countries toward stronger tobacco control by 2030, global agenda-setting exercises must be accompanied by improvements in the routine monitoring of smoking behavior, alongside improvements in policy formulation, enforcement, and compliance. Without valid and reliable data, these efforts risk being more aspirational than grounded in evidence-informed action. The advent of GATS, GYTS, and other multi-country survey series with tobacco modules substantially improved data availability on smoking prevalence, yet the disadvantages associated with such surveys – high cost, time lags between data collection, inconsistent questions across survey series, sample restrictions for young populations, and a reliance on self-reported smoking behavior – necessitate the development of robust, locally focused, timely, objective, and low-cost methods of tracking smoking trends. Development of low-cost routine monitoring systems is critical for tobacco control in low and low-middle SDI countries and territories, where the average time between surveys containing tobacco indicators was over 3 years, compared to less than one year in high SDI countries and territories. Supplementing surveys with biomarker collection for objective measurement of smoking status is essential because self-reported smoking prevalence is believed to be severely underestimating true smoking prevalence,[82–85] especially in population subgroups or places where tobacco use may not be culturally acceptable. Standardising tobacco use indicators will improve comparability of estimates across time and space, and will avoid increased uncertainty in estimates resulting from the need to adjust indicators to match a gold standard.

Limitations

Our findings should be interpreted taking into consideration the study's limitations. First, our exposure estimation focused on smoked tobacco, and did not include smokeless tobacco products and e-cigarettes; the inclusion of these tobacco products will occur in upcoming iterations of the GBD. Second, our definition of smoking exposure pertained to current daily smokers, and did not include occasional or former smokers, which may underestimate the attributable disease burden to smoking, especially among populations who tend to be less likely to smoke daily, such as women, children and young adults, and individuals with less disposable income. Third, we did not account for the intensity or duration of smoking, another limitation that will be addressed in future rounds of the GBD. Fourth, we potentially introduced additional uncertainty when adjusting for alternative frequency-type definitions and by splitting aggregated data into more granular sex-specific age groups. Fifth, the study relied on self-reported data, and it is possible that reporting biases varied across countries and over time. Sixth, for long-term effects of smoking on cancers and chronic respiratory diseases, we used the smoking impact ratio method which estimates the lifetime cumulative effect of cigarette smoking using the proxy of observed lung cancer versus lung cancer in smokers and non-smokers. This method provides robust estimates of the burden of cancers related to tobacco but is not fully consistent with the GBD approach of estimating exposure independently of the outcomes affected by exposure. Also, the smoking impact ratio method is based on the cumulative effect of cigarette smoking rather than all types of tobacco smoking, and may be less robust for geographies where non-smoker lung cancer may be significantly affected by household air pollution, ambient air pollution, or other factors. With increased data on smoking behaviors, including duration and intensity of use, direct estimation of attributable burden will be incorporated in future iterations of the GBD. Seventh, our burden estimates are likely underestimates because relative risk values used for estimating PAFs may not fully represent all possible risk-outcome pairs experienced by sex, age group, and over time.[86] We substantially expanded our database for smoking risk-outcome pairs for GBD 2015, and plan to continue such efforts in future GBD analyses. Additionally, we did not include the effects of maternal smoking on adverse birth outcomes. Also, burden estimates did not account for the effect of both indoor and outdoor air pollution potentiating risks. Finally, minimal risk-outcome data were available for populations younger than 30 years, and therefore burden attribution was limited to age groups 30 and older. As more data become available for health outcomes associated with smoking at younger ages, such attribution will occur within GBD.

Conclusion

Despite over fifty years of anti-tobacco efforts, smoking remains a leading global risk factor. Its toll will remain substantial without more concerted policy initiatives, policy compliance and enforcement, and sustained political will to offset commercial interests. Despite progress in some settings, the war against tobacco is far from won, particularly in the countries with the highest numbers of smokers. The staggering toll of smoking on health echoes well beyond the individual, especially as tobacco threatens to exact long-term financial and operational burdens on already resource-constrained health systems. In order to significantly and permanently bend the global tobacco epidemic's trajectory, a renewed and sustained focus is needed on comprehensive tobacco control policies around the world. Success is possible, but requires effective and aggressively enforced policies and laws. Intensified efforts are also greatly needed to keep smoking prevalence rates low in populations which have not experienced a devastating epidemic yet, and to prevent children, adolescents, and young adults from starting to smoke.

Declaration of interests

We declare that we have no competing interests.

Figures and tables

Figure 1. Age-standardised prevalence of daily smoking for men (A) and women (B), in 2015. ATG=Antigua and Barbuda; VCT= Saint Vincent and the Grenadines; BRB=Barbados; COM=Comoros; DMA=Dominica; GRD=Grenada; MDV=Maldives; MUS=Mauritius; LCA=Saint Lucia; TTO=Trinidad and Tobago; TLS=Timor-Leste; SYC=Seychelles; W Africa=Western Africa; E Med.=Eastern Mediterranean; MLT=Malta; SGP=Singapore; MHL=Marshall Islands; KIR=Kiribati; SLB=Solomon Islands; FSM=Federated States of Micronesia; VUT=Vanuatu; WSM=Samoa; FJI=Fiji; TON=Tonga.

Figure 2. Prevalence of daily smoking across birth cohorts over time, at the global level and by SDI quintile, for men (A) and women (B). Birth cohorts are colour-coded by five-year intervals, with the most recent birth cohort in red (2005) to the least recent birth cohort in dark blue (1910). Each dot represents the prevalence of daily smoking for a given birth cohort and age group. SDI = Socio-demographic Index.

Figure 3. Rankings of smoking as a risk factor for all-cause, all-age attributable DALYs for both sexes combined in 1990 (A), 2005 (B), and 2015 (C). DALYs = disability-adjusted life-years. ATG=Antigua and Barbuda; VCT= Saint Vincent and the Grenadines; BRB=Barbados; COM=Comoros; DMA=Dominica; GRD=Grenada; MDV=Maldives; MUS=Mauritius; LCA=Saint Lucia; TTO=Trinidad and Tobago; TLS=Timor-Leste; SYC=Seychelles; W Africa=Western Africa; E Med.=Eastern Mediterranean; MLT=Malta; SGP=Singapore; MHL=Marshall Islands; KIR=Kiribati; SLB=Solomon Islands; FSM=Federated States of Micronesia; VUT=Vanuatu; WSM=Samoa; FJI=Fiji; TON=Tonga.

Figure 4 Decomposition of changes in all-cause DALYs attributable to smoking from 2005 to 2015, by SDI, for men (A) and women (B). SDI quintiles are reported in order of the number of total all-cause, all-age DALYs attributable to smoking in 2015. Changes due to population growth, population aging, risk exposure (smoking prevalence), and the risk-deleted DALY rate are shown. Locations are reported in order of the number of attributable DALYs for both sexes in 2015. DALYs = disability-adjusted life-years. SDI = Socio-demographic Index.

Table 1. Age-standardised prevalence of daily smoking in 2015 and percent change in age-standardised prevalence from 1990-2015, 1990-2005, and 2005-2015 for men and women. For percent change estimates, red indicates an increase in prevalence, blue indicates a decrease in prevalence, and bold indicates a statistically significant change. 95% uncertainty intervals are reported in parentheses: (lower, upper).

Table 2. Size of the smoking population, prevalence, and 1990-2015 percent change in prevalence, by sex, for the ten countries with the largest smoking populations and globally. Age-standardised estimates and estimates for the 15-19 age group are reported. Overall rank is calculated based on the size of the smoking population, both sexes and all ages (10+) combined. Ages 15-19 rank is calculated based on the size of the smoking population aged 15-19, both sexes combined. For percent change estimates, red indicates an increase in prevalence, blue indicates a decrease in prevalence, and bold indicates a statistically significant change. 95% uncertainty intervals are reported in parentheses: (lower, upper).

Table 3. All-cause all-age (30+) deaths and DALYs and all-cause age-standardized mortality and DALY rates (per 100) in 2015 for men and women. 95% uncertainty intervals are reported in parentheses: (lower, upper).

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