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Future smoking prevalence by socioeconomic status in England: a computational modelling study

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ABSTRACT

Background The difference in smoking across socioeconomic groups is a major cause of health inequality. This study projected future smoking prevalence by socioeconomic status, and revealed what is needed to achieve the tobacco-free ambition (TFA) by 2030 in England.

Methods Using data from multiple sources, the adult (≥ 18 years) population in England was separated into subgroups by smoking and highest educational qualification (HEQ). A discrete time state-transition model was used to project future smoking prevalence by HEQ deterministically and stochastically.

Results In a status quo scenario, smoking prevalence in England is projected to be 10.8% (95% uncertainty interval: 9.1% to 12.9%) by 2022, 7.8% (5.5% to 11.0%) by 2030 and 6.0% (3.7% to 9.6%) by 2040. The absolute difference in smoking rate between low and high HEQ is reduced from 12.2% in 2016 to 7.9% by 2030, but the relative inequality (low/high HEQ ratio) is increased from 2.48 in 2016 to 3.06 by 2030. When applying 2016 initiation/relapse rates, achievement of the TFA target requires no changes to future cessation rates among adults with high qualifications, but increased rates of 37% and 149%, respectively, in adults with intermediate and low qualifications.

Conclusions If the current trends continue, smoking prevalence in England is projected to decline in the future, but with substantial differences across socioeconomic groups. Absolute inequalities in smoking are likely to decline and relative inequalities in smoking are likely to increase in future. The achievement of England's TFA will require the reduction of both absolute and relative inequalities in smoking by socioeconomic status.

INTRODUCTION

Smoking continues to be the leading cause of avoidable mortality and morbidity worldwide.¹ For some years a 'tobacco-free' ambition (TFA) or 'tobacco endgame' has been proposed, to achieve a smoking prevalence of $\leq 5\%$ across all population subgroups in a country.² Smoking prevalence among adults in England has declined from 20% in 2011 to 14.4% in 2018.³ The Tobacco Control plan in England aimed to reduce overall smoking prevalence further to 12% by the end of 2022,⁴ and the UK government has recently set an ambition to achieve a 'smoke-free' England by 2030.⁵

The difference in smoking prevalence across socioeconomic groups is a major cause of existing health inequality, and a systematic review concluded that 'there has been no reduction in smoking inequalities in the UK in recent years'.⁶

Smoking prevalence in 2018 in England was much higher in adults classified as routine and manual workers (25%), compared with those in managerial and professional occupations (10%).³ In addition, adults with no formal qualification have much higher smoking prevalence than those with a degree qualification (29% vs 7% in 2018) in England.³

Several studies have projected future smoking prevalence, as well as the benefits of reduced smoking prevalence in the UK.⁷⁻⁹ However, smoking prevalence by socioeconomic circumstance in England has not been evaluated in modelling studies. In this study, we developed a computational model to project future smoking prevalence by educational qualifications in England, to compare results of different projection scenarios, and to understand what is needed to achieve the TFA by 2030 in terms of smoking initiation, relapse and cessation-related rates.

METHODS

Model framework

A discrete time state-transition model developed in our previous study¹⁰ was revised to incorporate socioeconomic status (SES) for adults in England.¹¹ Briefly, the adult population in England was categorised into subgroups by sex, age, highest level of educational qualification (HEQ) and smoking status. The modelling process updated the population subgroups annually according to the probability of death, transitions across HEQs and smoking status. The model's main structure and data sources are available in online supplementary appendix 1.

There are several commonly used socioeconomic measures in the UK including the Index of Multiple Deprivation,¹² and the National Statistics Socioeconomic classification.¹³ An individual's HEQ can also be used to represent SES.¹⁴ Owing to data availability and modelling simplicity, we used the highest qualifications¹⁴ and separated adults (≥ 18 years old) in England into three socioeconomic categories: high, intermediate and low qualifications. Adults in the high qualification category (HEQhigh) have a degree or higher education equivalent qualifications. Intermediate qualifications (HEQinter) include the General Certificate of Education Advanced Level (A-level) or equivalent, and low qualifications (HEQlow) include the General Certificate of Secondary Education (GCSE) or lower or no formal qualifications. The A-level and GCSE in England are equivalent to, respectively, the high school and middle school degree in the USA.



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Data sources

The simulation modelling started from the year 2013. We obtained the sex-age-specific population and death rates in 2013 in England from the Office for National Statistics.¹⁵ The sex-age-specific population in England were further categorised into three socioeconomic subgroups: adults with high, intermediate or low qualifications. Self-reported smoking prevalences by qualification were obtained from Annual Population Surveys from 2013 to 2017 in the UK. To facilitate simulation modelling, the observed age-sex-specific smoking prevalence rates during 2013–2017 were smoothed using simple linear regression (see online supplementary appendix 1).

We used a negative exponential model¹⁶ to estimate the risk of relapse to smoking for former smokers, which was calibrated according to data presented in a study by Stapleton and West.¹⁷ The number of 18 years old in England was from the Office for National Statistics,¹⁵ and added as an exogenous input to the simulated population each year. Most new smokers (including those who initiated smoking before the age of 18) in the model were exogenously added 18-year-old smokers. Additional new smokers were initiated between the ages of 18–24, based on data from a study by Vugrin *et al*,¹⁸ and calibrated according to changes in observed smoking prevalence between two adjacent ages. We obtained data on estimates of relative risk of all-cause mortality for current smokers versus never smokers from 2014 report of the surgeon general.¹⁹ We adopted a negative exponential model, calibrated based on data presented in Vugrin *et al*,¹⁸ to estimate relative risks of all-cause mortality by time since cessation. We defined former smokers as those who stopped smoking for ≥ 12 months, and used a modelling approach to estimating cessation rate between two adjacent years, given other inflow to and outflow from current smokers,¹⁰ during 2013–2016 (online supplementary appendix 1).

Outcome measures

The model's primary outcome is smoking prevalence by HEQ in England. We defined smoking prevalence rate as the proportion of current smokers in the population at the beginning of a year, which depends on smoking prevalence, initiation, relapse, cessation and death rates in the past year. The number of quitters in year t was estimated based on the change in observed smoking prevalence between year t and $t+1$, given estimated smoking relapse, new take-ups and death (online supplementary appendix 1). The model was historically validated by comparing estimated and observed smoking prevalence rates by sex, age and HEQ in England during 2013–2017. Because the beginning of year $t+1$ is equivalent to the end of year t , and the proposed TFA target is to have a smoking prevalence of $\leq 5\%$ by the end of 2030, results by the beginning of year $t+1$ were presented as by the end of year t in this study. We reported both absolute and relative inequalities in smoking prevalence. The absolute inequality in smoking is the difference in smoking rate between adults with lower and higher qualifications. The relative inequality was defined as the ratio of smoking rates in the lower and higher qualification groups.

Projection scenarios and uncertainty

The developed model can be run in two modes: predictive and target.⁷ In prediction mode, future smoking prevalence rates from 2017 to 2040 in England were projected according to different scenarios regarding smoking initiation, relapse and quitting rates. In status quo scenario, future smoking prevalence was projected using model parameters as in 2016, assuming

no changes in initiation, relapse and cessation rates. To answer additional 'what-if' questions, we estimated impacts of 20%, 40% or 60% reductions in initiation, relapse and cessation rates on future smoking prevalence. In target mode, it was assumed that smoking prevalence rates will be $\leq 5\%$ (ie, achieving the TFA) for all age, sex and HEQ subgroups by the end of year 2030. We estimated cessation rates that were required each year to achieve the TFA, given different levels of changes in initiation and relapse rates (see online supplementary appendix 2 for details). Target projection provides useful estimates of the changes needed in initiation, relapse and cessation to achieve the smoking prevalence target.

The model can be used to conduct deterministic sensitivity analyses or probabilistic Monte Carlo simulations. Deterministic sensitivity analyses evaluated the impacts of different rates of initiation, relapse and cessation on future smoking prevalence (online supplementary appendix 2). Probabilistic Monte Carlo simulations were conducted according to uncertainty distributions of key input parameters, including relative risks of all-cause mortality, initiation, relapse and cessation rates (online supplementary appendix 1). The uncertainty in estimates of relative risks was reflected by their 95% CIs. We used the beta-PERT distribution (with $\lambda=1$) to evaluate uncertainty in estimates of smoking initiation, relapse and cessation rates, assuming the parameters ranged from 50% lower to 150% higher than the most likely estimates. Each probabilistic simulation involved 5000 iterations, and each iteration used a different set of randomly selected values for key input parameters. Of the 5000 simulation results, the most likely estimate of an outcome was the median, and 95% uncertainty interval (UI) were based on the 2.5% and 97.5% percentiles.

There was no direct patient and public involvement in this study.

RESULTS

Estimated smoking initiation and cessation during 2013–2016

Smoking rates during 2012–2016 declined by 21%, 17% and 18%, respectively, in adults with high, intermediate and low qualifications (table 1). The estimated overall initiation rate among 18–19 years old was reduced by 25%, from 15.2% in 2013 to 11.4% in 2016, although initiation rates were much higher among lower qualification groups (online supplementary appendix 3). Given changes in smoking prevalence and other modelling parameters, the estimated cessation rate in 2016 was 12.1%, 7.1% and 7.6%, respectively, among current smokers with high, intermediate and low qualifications (online supplementary appendix 3).

Table 1 Observed and projected future smoking prevalence (%) in England

Scenario	HEQhigh	HEQinter	HEQlow	Total
Baseline (2012–2016)				
2012	10.4	18.9	25.1	18.6
2016	8.2	15.6	20.5	15.0
Status quo projection (Monte Carlo simulation)*				
2022	5.7 (4.5–7.2)	11.9 (10.0–14.1)	15.5 (13.1–18.3)	10.8 (9.1–12.9)
2030	3.8 (2.5–6.0)	9.2 (6.5–12.5)	11.7 (8.4–16.0)	7.8 (5.5–11.0)
2040	2.7 (1.5–5.1)	7.6 (4.7–11.3)	9.4 (5.9–14.5)	6.0 (3.7–9.6)

*Results of Monte Carlo simulation—median estimates (95% uncertainty intervals). HEQhigh, high educational qualification; HEQinter, intermediate educational qualification; HEQlow, low educational qualification.

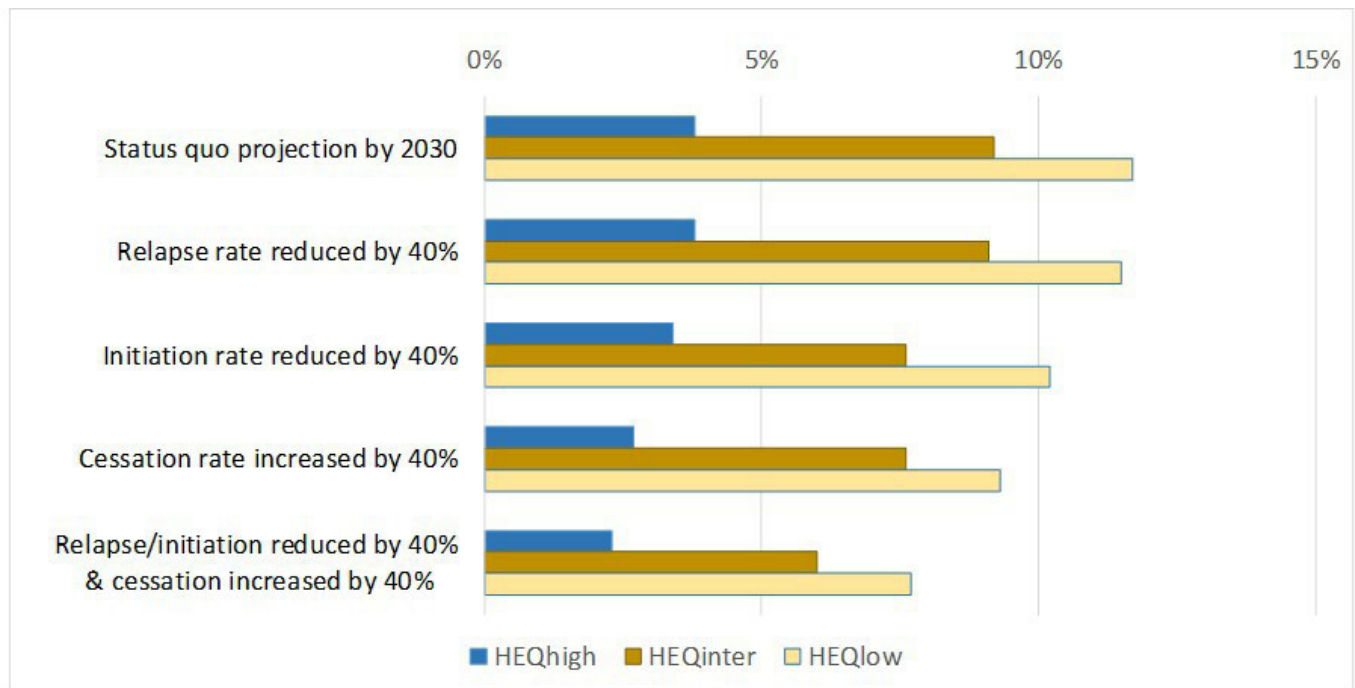


Figure 1 Projected smoking prevalence by 2030 in England—results of selected scenarios. HEQhigh, high educational qualification; HEQinter, intermediate educational qualification; HEQlow, low educational qualification.

Projections of future smoking prevalence

Under a status quo scenario, the overall smoking prevalence in England is projected to be 10.8% (95% UI: 9.1% to 12.9%) by 2022, 7.8% (5.5% to 11.0%) by 2030 and 6.0% (3.7% to 9.6%) by 2040. Under the status quo projection, the TFA target by 2030 is projected to be achieved in adults with HEQ (3.8%), but not in those with intermediate (9.2%) and low (11.7%) educational qualifications (table 1).

Projected smoking rates under all evaluated scenarios are presented in online supplementary appendix 4, and results of selected scenarios are shown in figure 1. As expected, increased cessation rates and reduced initiation and relapse rates are associated with lowered smoking prevalence in future. The impact on smoking rates by reducing relapse rates is relatively small, compared with the same proportional increase in cessation rates or reduction in initiation rates (figure 1). The increase in cessation rates can lower smoking prevalence quickly, and the reduction in initiation rates reduces long-term smoking prevalence in the population (online supplementary appendix 4). Clearly, a combination of increased cessation rates and reduced initiation/relapse rates will have the greatest impact on future smoking prevalence. Of the evaluated projective scenarios, the overall smoking prevalence would be <5% by 2030 under a scenario that combines a 60% increase in cessation rates and 60% reduction in initiation and relapse rates (online supplementary appendix 4).

Absolute and relative inequalities in smoking prevalence

Under all projection scenarios evaluated, absolute differences in smoking prevalence between HEQ groups will be reduced in the future (table 2 and online supplementary appendix 4). The difference in smoking prevalence between low and high qualifications will be reduced from 12.2% in 2016 to 7.9% by 2030, in the status quo projection. If initiation and/or relapse were reduced and cessation increased, the absolute differences in smoking rate between HEQ groups would be further reduced. However, the relative inequalities in smoking prevalence are likely to increase,

given the current trend or similar changes in initiation, relapse and cessation rates. The ratio of smoking prevalence between the low and high qualification will increase from 2.48 in 2016 to 3.06 by 2030 in the status quo projection. If initiation and relapse rates were reduced by 40% and cessation rate increased by 40% for the whole population, the ratio of smoking rates between the HEQlow and HEQhigh group would increase from 2.48 in 2016 to 3.35 by 2030. The relative inequalities in smoking prevalence are reduced in the target projection, in which the smoking prevalence rate will be ≤5% by 2030 for all HEQ subgroups (table 2).

Cessation, initiation and relapse rates required to achieve the TFA target

The TFA target (smoking rate <5%) is achieved in the HEQhigh group by 2030 in the status quo projection. Given the same initiation and relapse rates as in 2016, cessation rates during 2017–2030 will need to be increased by 37% (9.2% vs 6.7%) and by 149% (18.2% vs 7.3%), respectively, among smokers with intermediate and low qualifications (table 3). As expected, reduced initiation and relapse rates are associated with lowered cessation rates required to achieve the TFA. Compared with reduced initiation rates, the same proportional reductions in relapse rates tended to have greater impacts on the cessation rates required to achieve the TFA. However, the increase in cessation rates is essential for achieving the TFA in the low qualification group. Even if both the initiation and relapse rates were reduced by 40%, the cessation rates would still need to be increased by 70% (12.4% vs 7.3%) for smokers with low qualifications (table 3).

In the status quo scenario, the projected total number of quitters each year in England will decrease from around 568 000 in 2016 to 397 000 on average during 2017–2030 (table 3), as a consequence of the shrinking population of smokers over time. To achieve the TFA target, given the same initiation and relapse rates as in 2016, the average number of quitters each year will

Table 2 Estimated smoking prevalence, absolute and relative inequalities—results of selected scenarios*

Scenario	Smoking prevalence			HEQinter versus HEQhigh		HEQlow versus HEQhigh	
	HEQhigh	HEQinter	HEQlow	Rate difference	Rate ratio	Rate difference	Rate ratio
Baseline							
2013	10.4%	18.9%	25.1%	8.5%	1.82	14.7%	2.41
2016	8.2%	15.6%	20.5%	7.4%	1.90	12.2%	2.48
Status quo projection							
2030	3.8%	9.2%	11.7%	5.3%	2.40	7.9%	3.06
2040	2.7%	7.5%	9.4%	4.8%	2.79	6.7%	3.48
20% reduction in initiation/relapse, and 20% increase in cessation rate							
2030	3.0%	7.5%	9.6%	4.5%	2.53	6.6%	3.23
2040	1.9%	5.8%	7.1%	3.9%	3.11	5.2%	3.83
40% reduction in initiation/relapse, and 40% increase in cessation rate							
2030	2.3%	6.0%	7.7%	3.7%	2.62	5.4%	3.35
2040	1.2%	4.2%	5.2%	3.0%	3.41	3.9%	4.14
60% reduction in initiation/relapse, and 60% increase in cessation rate							
2030	1.8%	4.6%	6.0%	2.9%	2.64	4.2%	3.41
2040	0.8%	2.9%	3.5%	2.1%	3.65	2.7%	4.39
TFA target projection							
2030	3.3%	4.6%	4.3%	1.3%	1.39	1.0%	1.31
2040	1.8%	3.4%	3.0%	1.6%	1.88	1.2%	1.67

*Results of all scenarios evaluated are presented in online supplementary appendix 4.

HEQhigh, high educational qualification; HEQinter, intermediate educational qualification; HEQlow, low educational qualification; TFA, tobacco free ambition.

need to be about 32% (111 000 vs 84 000) and 54% (314 000 vs 204 000) higher than that in the status quo scenario, respectively, among adults with intermediate and low qualifications

(table 3). If initiation and relapse rates were reduced, the average number of quitters required each year during 2017–2030 would be correspondingly reduced. If initiation and relapse rates are

Table 3 Cessation rates required to achieve the tobacco-free ambition (TFA) by 2030 in England, according to different initiation and relapse rates

Scenario	HEQhigh	HEQinter	HEQlow	Total
Cessation rate required to achieve TFA				
Status quo projection by 2030	12.0%	6.7%	7.3%	8.0%
Target projection by 2030:				
Initiation and relapse rate as in 2016	11.2%	9.2%	18.2%	13.5%
20% reduction in initiation rate	11.2%	9.0%	16.9%	13.0%
20% reduction in relapse rate	10.5%	8.2%	16.4%	12.3%
20% reduction in initiation and relapse rate	10.5%	8.1%	15.1%	11.7%
40% reduction in initiation rate	11.2%	8.9%	15.4%	12.3%
40% reduction in relapse rate	9.8%	7.4%	15.0%	11.3%
40% reduction in initiation and relapse rate	9.8%	7.2%	12.4%	10.2%
60% reduction in initiation rate	11.2%	8.7%	13.9%	11.7%
60% reduction in relapse rate	9.2%	6.8%	14.1%	10.6%
60% reduction in initiation and relapse rate	9.2%	6.4%	10.2%	8.8%
Average no of quitters required each year (x1000)				
Baseline in 2016	163	114	291	568
Status quo scenario (during 2012–2016)	108	84	204	397
Target projection (during 2012–2016):				
Initiation and relapse rate as in 2016	106	111	314	530
20% reduction in initiation rate	106	110	306	521
20% reduction in relapse rate	99	104	297	499
20% reduction in initiation and relapse rate	99	103	289	490
40% reduction in initiation rate	106	109	297	512
40% reduction in relapse rate	92	97	281	470
40% reduction in initiation and relapse rate	92	96	265	453
60% reduction in initiation rate	105	108	289	503
60% reduction in relapse rate	86	91	266	443
60% reduction in initiation and relapse rate	85	89	243	417

HEQhigh, high educational qualification; HEQinter, intermediate educational qualification; HEQlow, low educational qualification; TFA, tobacco free ambition.

reduced, the average number of quitters required each year to achieve the TFA target will be correspondingly reduced during 2017–2030 (table 3).

DISCUSSION

If current trends continue, smoking prevalence in England is projected to be 10.8% (95% UI 9.1% to 12.9%) by 2022, 7.8% (95% UI 5.5% to 11.0%) by 2030 and 6.0% (95% UI 3.7% to 9.6%) by 2040. Public Health England projected that smoking rate would be between 9.8% and 15.5% by 2022,²⁰ which is slightly higher than ours (9.1% to 12.9%). Although future smoking prevalence in England is likely to continue to decline, differences in smoking across socioeconomic groups remain noticeable.

Our results indicated the importance of considering both absolute and relative inequalities in smoking.²¹ Absolute inequalities in smoking are projected to decline in England, but relative inequalities in smoking are likely to increase under the status quo and other projection scenarios. Of the evaluated scenarios, only the achievement of the TFA target (smoking prevalence $\leq 5\%$) for all HEQ groups reduces relative inequalities in smoking. The reduction in absolute inequalities is attributable to reduced smoking rates in all HEQ groups, and the increase in relative inequalities is mainly due to the different speed of declining in smoking prevalence by HEQ. For example, smoking prevalence is projected to decline by 54%, 41% and 43% during 2016–2030, respectively, in adults with high, intermediate and low qualifications (table 1). Therefore, both absolute and relative inequalities in smoking are relevant to tobacco control policies, and it is important to be transparent about how inequalities are measured in studies.

Increased cessation and reduced initiation/relapse rates are associated with lowered smoking prevalence in future. According to results of evaluated projection scenarios, reduction in relapse rates may have relatively small impact on future smoking prevalence, compared with the same proportional increase in cessation rates or reduction in initiation rates. In addition, increased cessation rates may start to lower smoking prevalence among adults immediately, while the impacts of changes in initiation rates on smoking prevalence may emerge after some years. To achieve the TFA target by 2030, given the same initiation and relapse rates as in 2016, it is projected that smoking cessation rates need to be increased by 37% (from 6.7% to 9.2%) and by 149% (from 7.3% to 18.2%), respectively, in adults with intermediate and low qualifications. If initiation and relapse rates could be reduced by 40%, the cessation rate would need to increase by only 7% in the HEQinter group and by 70% in the HEQlow group.

Implications on tobacco control policies

The recent rapid decline in smoking prevalence in England is likely a consequence of multiple tobacco control measures, including the NHS Stop Smoking Services established since 2000/2001,¹⁰ the ban on smoking in public places in 2007,²² mass media campaign,²³ tobacco taxing,²⁴ increase in the legal age for the sale of cigarettes,²⁵ tobacco point of sale display bans,²⁶ the smoking ban in cars with children²⁷ and use of electronic cigarettes.²⁸ According to the tobacco control plan for England, the government's short-term target is to reduce smoking prevalence to $\leq 12\%$ by the end of 2022,⁴ and the longer-term target is to achieve the TFA target (smoking prevalence $\leq 5\%$) by the end of 2030.⁵ With a continuation of the current trend, we found that the short-term target of 12% for overall smoking prevalence by

2022 may be achievable, although the smoking rate in adults with low qualifications (15.5%) remains $>12\%$. In the status quo projection, the TFA target will not be achieved by 2030, due to the high smoking rates in adults with intermediate and low qualifications.

The government's tobacco control plan for England focuses on four main themes and related actions, including prevention first, supporting smokers to quit, eliminating variations in smoking rates and effective enforcement.⁴ It is unclear whether these existing tobacco control measures could sufficiently boost the reduction in future smoking prevalence in adults with intermediate and low qualifications. To achieve the TFA target, it is required to considerably increase cessation rates, and reduce initiation/relapse rates, in the HEQinter and HEQlow groups. Currently available evidence indicates that inequalities in smoking may be reduced by increasing price/tax of tobacco products,²⁹ and by targeting cessation services to individual smokers with low SES.³⁰ According to currently available evidence,²⁸ the use of electronic cigarettes has been promoted for smoking cessation in England.³¹ However, possible impacts of the use of electronic cigarettes on social inequalities in smoking remain uncertain.³²

The population of smokers in England is shrinking over time, following continued declining in smoking prevalence. To achieve the TFA target by 2030, the average number of quitters required each year during 2017–2030 needs to be increased by 8% in the HEQlow group, compared with that in 2016. The estimated number of quitters required to achieve the TFA may be used to plan stop smoking service by focusing on smokers with low educational qualifications.

Because of considerable differences in future smoking prevalence across socioeconomic subgroups, it calls into question the use of the overall smoking prevalence as a tobacco control target. Future tobacco control plans need to be more specific in terms of socioeconomic characteristics.

Strengths and limitations

This is the first modelling study to project future smoking prevalence by SES in England. The model can be run both deterministically and probabilistically, to explore outcomes of different projection scenarios, and be used to answer 'what-if' tobacco control policy questions.

We used educational qualification as the measure of SES in the present study, because the use of other measures of SES would have added substantial complexity to the model. Another limitation was that data on smoking prevalence by the highest qualification from Annual Population Surveys were accessible only for a period of 5 years during 2013–2017. Also, we found only limited data available on relative risks of all-cause mortality, initiation and relapse rates. Furthermore, the observed smoking prevalence rates are subject to sampling errors. To deal with possible sampling error and facilitate the modelling process, the observed rates of sex-age-specific smoking prevalence rates by HEQ during 2013–2017 were smoothed using simple linear regression. Finally, we explored only a few assumed projection scenarios, although there are numerous possible mixes of different changes in future smoking related parameters. However, the established model could be updated with new data and used to explore other projection scenarios according to the needs of making policy decisions.

CONCLUSIONS

If the current trends continue, smoking prevalence in England is projected to decline during 2017–2040, but with substantial

differences across socioeconomic subgroups. Absolute inequalities in smoking are projected to decline and relative inequalities in smoking to increase in future, under the status quo and other projection scenarios. The achievement of the TFA (smoking prevalence $\leq 5\%$) for England will require the reduction of both absolute and relative inequalities in smoking by SES.

What this paper adds

What is already known on this subject

- ▶ The difference in smoking across socioeconomic groups is a major cause of health inequality.
- ▶ The UK government has set a tobacco-free ambition (TFA) to bring smoking prevalence to $\leq 5\%$ in England by 2030.

What important gaps in knowledge exist on this topic

- ▶ We lack robust estimates for future smoking prevalence by socioeconomic status (SES) in England, and the implication of SES inequalities in smoking for the TFA target.

What this paper adds

- ▶ The achievement of the TFA target in England will require the reduction of both absolute and relative inequalities in smoking by SES.
- ▶ To achieve the TFA target by 2030, cessation rates need to be much increased, and initiation/relapse rates reduced, in adults with intermediate and low educational qualifications.

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