Characterisation of smoking behaviour across the life course and its impact on decline in lung function and all-cause mortality: evidence from a British birth cohort

S Clennell,1 D Kuh,1 J M Guralnik,2 K V Patel,2 G D Mishra1

ABSTRACT

Objectives: To describe smoking trajectories from early adolescence into mid-life and to examine the effects of these trajectories on health and all-cause mortality.

Methods: A nationally representative birth cohort study including 3387 men and women followed up since their birth in 1946 in England, Scotland and Wales. The main outcome measure is all-cause mortality by age 60 years and rate of decline in forced expiratory volume in 1 second (FEV1).

Results: Eighteen per cent of the sample were categorised as lifelong smokers (smokers at all six waves at ages 20, 25, 31, 36, 43, 53 years), of whom 90% had begun smoking by age 18 years. By age 60 years, 10% of all lifelong smokers had died. They had a threefold increase in mortality rate compared with never smokers (hazard ratio (HR) 3.2, 95% confidence interval (CI) 2.1 to 4.8). For predominantly smokers (smokers for at least four of the six data collections), mortality rate remained higher than never smokers (HR 1.6, 95% CI 1.0 to 2.5).

Predominantly non-smokers did not differ from those who never smoked (HR 1.3, 95% CI 0.9 to 2.0). Using the most recent smoking status available, current smokers had more than double the risk of mortality compared with never smokers (HR 2.4, 95% CI 1.6 to 3.5). Lifelong smokers and predominantly smokers had a greater rate of decline in lung function than never smokers (regression coefficients −18 ml/year, 95% CI −22 to −13; −6, 95% CI −10.3 to −1.7 respectively). For current smokers, the decline was 8.4 ml/year (95% CI −12.0 to −5.0) faster than never smokers.

Conclusions: The strength and differentiation of adverse effects identified by using simplified smoking behaviours has highlighted the advantages of obtaining further information on lifelong smoking behaviour from former smokers, rather than just current smoking status.

Smoking is a major cause of global mortality and the single most important risk factor in developed countries. Total tobacco-attributable deaths are projected to rise from 5.4 million in 2005 to 6.4 million in 2013 and 8.3 million by 2030 under the baseline scenario of Mathers and Loncar.1 In the UK, it is estimated that each year 114 000 die from smoking-related causes, or about a fifth of all UK deaths.2

There have also been several attempts to characterise adolescent smoking behaviour.20–24 In 2004, Audrain-McGovern and colleagues identified four adolescent smoking trajectories (never smokers, experimenters, earlier/faster adopters and later/slower smoking adopters).23 These smoking trajectories had significantly different rates and intensity of smoking progression,23 but few studies have prospective longitudinal data to follow such trajectories into adult life.

The Medical Research Council National Survey of Health and Development (NSHD) is a population-based birth cohort study that provides an opportunity to study lifelong smoking behaviour and its influence on mid-life health outcomes.25
The aims of this paper are: (1) to describe the main smoking trajectories in this cohort from early adolescence into mid-life; (2) to examine the relationships between these smoking trajectories and adult all-cause mortality to age 60 years and rate of change in lung function from age 43 to 53 years; and (3) to compare the strength of these relationships with those found using the most recent smoking status available and with those from smoking status assessed at 25 years of age.

METHODS

The NSHD is a social class stratified birth cohort of 5362 births (2815 men and 2547 women) in the first week of March 1946 in England, Scotland and Wales. There have been 21 follow-ups of the main cohort since their birth up to the most recent contact in 1999 at age 53 years. A total of 3035 cohort members (1472 men, 1563 women) provided information at age 53 years. This corresponds to a participation rate of 70.5% among those still alive and resident in England, Wales or Scotland, and 89.6% for whom contact was attempted. Contact was not attempted for individuals who had previously refused to take part (n = 648), were untraced since last contact at 43 years (n = 266), were living abroad (n = 583) or had already died (n = 476). Those who responded at age 53 years were in most respects representative of the national population of a similar age. Ethic approval for this study was given by the North Thames Multicentre Research Committee.

Current cigarette smoking status ("yes", "no") and the number of cigarettes smoked per day were obtained in six waves (at ages 20, 25, 31, 36, 43, 53 years). Cohort members who provided an affirmative response to being current cigarette smokers, regardless of the quantity of cigarettes smoked per day, were classified as "smokers", while those who provided a negative response were classified as "non-smoker". From age 36 onwards, research nurses obtained information on smoking during a home interview, while data from earlier years were collected by postal questionnaire. A total of 1845 (34%) participants provided information on smoking at all six waves, 2655 (49%) had missing information for at least one wave, and 882 (17%) failed to provide any smoking data (fig 1).

The sample for this analysis comprised those who provided data for at least three waves (n = 3387) and for whom missing data are not sequential (fig 1). Cohort members were classified into one of four smoking trajectories:

1. "Never smoker": a non-smoker at all available data collections
2. "Predominantly non-smoker": a non-smoker for at least three data collections
3. "Predominantly smoker": a smoker at four or more of the data collections
4. "Lifelong smoker": a smoker at all available data collections.

In cases where data were missing from one or more waves, classification was based on the smoking status at the majority of data collections. Thus, if at three out of four data collections the cohort member reported being a smoker, then they were classified as "predominantly smoker". To permit a comparison with results from the smoking trajectories, two single time point measures were also used: the most recent smoking status available from cohort members (including from those who had died) and smoking status at age 25 years.

Smoking dosage to age 53 years was measured by the average number of cigarettes smoked per day: determined from the pack–years of smoking calculated at each data collection. Age at which the cohort member began smoking was recorded retrospectively at age 20 years.

In order to evaluate the performance of the various measures of smoking behaviour, smoking-related health outcomes, namely all-cause mortality, and changes in lung function, were chosen. Since age 26 years, cohort members have been flagged for death notification on the National Health Service Central Register. In order to ensure that cohort members who died had provided sufficient information on smoking behaviour, time to all-cause mortality was taken from age 36 years onwards. Between 36 and 60 years, there were 211 deaths. Lung function was available to all cohort members and was denoted by forced expiratory volume in 1 second (FEV1) measured at ages 43 and 53 years using the Micromedical turbine electronic spirometer, administered by a trained nurse. The rate of lung function change per year over the two time.
points was used in the analysis (FEV$_1$ at 53 years–FEV$_1$ at 43 years/10), with a decline recorded as a negative value.

**Statistical analyses**

Cox proportional hazard models were used to investigate the relations between each measure of smoking behaviour and all-cause mortality.\textsuperscript{30} In order to obtain the hazard ratios (HRs) for all-cause mortality, follow-up time (in months) was from the cohort’s 36th birthday until the first of death, emigration or the end of March 2006, the cohort’s 60th birthday. If death had not occurred, follow-up was treated as censored. The assumption of proportional hazards (PH) was evaluated both by the inspection of the Kaplan–Meier survival curves and by testing the null hypothesis that the PH assumption holds for each measure of smoking behaviour. These were obtained from the statistical package STATA 8.2, commands \texttt{stphplot} and \texttt{stphtest} respectively.

Linear regression was used to examine the relation between rate of FEV$_1$ change from age 43 to 53 years and each measure of smoking behaviour. The regression coefficients and the 95% confidence intervals (CIs) were adjusted for FEV$_1$ at baseline (43 years) and height at age 53 years.\textsuperscript{18} As the main aim of this paper was to compare the results obtained from the various measures of smoking behaviour, rather than to examine the predictors of all-cause mortality or lung function, only results from univariable analyses were presented. All analyses were carried out on data from at least three waves (n = 3387). A sensitivity analysis was carried out by repeating all analyses on those with complete smoking status data (n = 1845). As the findings from these analyses were broadly similar, results from the larger sample size are presented here.

**RESULTS**

Based on the 1845 cohort members, who completed all six waves of questionnaires, the prevalence of smoking more than halved for men from 55% at age 20 years to 21% by age 53 years (fig 2). The reduction was less for women, declining from 49% at age 20 years to 24% at age 53 years. In this cohort, a higher proportion of smokers at age 25 years (p \textless 0.001) provided incomplete data (48%), compared with the never-smoking group (31%). Those with incomplete smoking data were more likely to be male (54% incomplete vs 47% complete), have primary or lower education level (72% vs 61%) and come from a manual social class background (37% incomplete vs 29% complete). Of the 3387 cohort members who provided information for smoking trajectories, there was only one for whom mortality status was not available.

More than one in four of the cohort members (28%) were lifelong non-smokers (table 1), with almost a third (32%) of all women belonging to this group, with almost a third (32%) of all women belonging to this group. Nearly a fifth (18%) of the sample were categorised as lifelong smokers, of whom 30% started smoking before age 16 years and 90% had begun by age 18 years. Of lifelong smokers, men were more likely to start smoking by age 16 years than women (56% vs 39%). In the predominantly non-smoking group, more than two out of three (67%) had already stopped at least once by 25 years, and only 5% were smokers at their most recent report. In addition, only one individual had smoked more than 15 cigarettes per day. In contrast, around one out of five predominantly smokers (17%)...
and three out of four of the lifelong smokers had 15 or more cigarettes per day. Of those in the cohort that were recorded as being former smokers for their most recent status, 50% were predominantly smokers over their lifetime.

**All-cause mortality**

For those with smoking trajectory data, 211 study members had died between the age of 36 and 60 years: 120 men and 91 women. Of lifelong smokers, the probability of surviving past the age of 60 years was 0.88 compared with 0.96 for never smokers (fig 5). From table 2, this corresponds to a threefold increase in the hazard ratio for lifelong smokers (HR = 3.2, 95% CI 2.1 to 4.8). Predominantly non-smokers did not differ significantly from those who never smoked. For predominantly smokers, the mortality rate was almost halved compared with lifelong smokers, but remained 60% higher than never smokers.

Using the most recent smoking status available, current smokers had more than double the risk of mortality by age 60 years compared with those who had never smoked, but less than the hazard ratio indicated by lifelong smoking status from trajectories. Former smoking status suggested a higher risk of mortality than the hazard ratio indicated by lifelong smoking status from 60 years compared with those who had never smoked. Former smokers recorded no significant difference in rate of decline in lung function between predominantly smokers and never smokers. From the most recent smoking status available, the lung function of current smokers was found to have declined at a rate of 8.4 ml/year (95% CI −18.0 to 12.0) compared with never smokers, and three times that estimated between predominantly smokers and never smokers (table 3).

No evidence for a difference in the rate of decline was found between predominantly non-smokers and never smokers. From the most recent smoking status available, the lung function of current smokers was found to have declined at a rate of 8.4 ml/year (95% CI −12.0 to −5.0) faster than never smokers. Former smokers recorded no significant difference in rate of decline in lung function relative to those who had never smoked. Similar results were obtained for rates of change in lung function using smoking status at age 25 years.

**Rate of change in lung function from age 43 to 53 years**

Lifelong smokers had a marked decline in lung function between 43 and 53 years (12.0 ml/per year, 95% CI −22.3 to −2.4) compared with never smokers, and three times that estimated between predominantly smokers and never smokers (table 3). No evidence for a difference in the rate of decline was found between predominantly non-smokers and never smokers. From the most recent smoking status available, the lung function of current smokers was found to have declined at a rate of 8.4 ml/year (95% CI −12.0 to −5.0) faster than never smokers. Former smokers recorded no significant difference in rate of decline in lung function relative to those who had never smoked. Similar results were obtained for rates of change in lung function using smoking status at age 25 years.

**DISCUSSION**

Prospective data from the NSHD, spanning more than 30 years, has produced stark evidence for the differential impact of cigarette smoking behaviours on mortality rate and lung function decline. Moreover, the strength of this evidence differs according to the way smoking behaviour is characterised.

Lifelong smokers, as classified by their smoking trajectory, were at the greatest risk of all-cause mortality and, by age 60 years, more than 10% had died. Lifelong smokers also had the greatest rate of lung function decline between ages 43 and 53 years compared with those who had never smoked. Weaker effects were identified by using the single time point measures of either current (most recent) smoking status or smoking status at age 25 years. Smoking trajectories also quantified the impact of cessation by distinguishing the risk of mortality and decline in lung function between those who had been predominantly smokers throughout their life from predominantly non-smokers.

These results are broadly consistent with other studies. Doll et al. found that smoking from early adult life among British doctors tripled age-specific mortality rates compared with lifelong non-smokers. The ACS CPS-II cohort study found that continuing smokers had around twice the overall mortality rates of those who had never smoked. There is also general

![Figure 3: Kaplan–Meier estimates of the proportion of cohort members who are still alive by the smoking trajectories (n = 3286).](image-url)
agreement with other studies on the impact of quitting smoking. In the study of British doctors, it was determined that cessation by age 50 years halved the increased risk, and cessation by 50 years avoided almost all of it.\textsuperscript{39} Data from the ACS CPS-II also revealed that those who quit smoking before age 50 years halved the risk of dying in the following 15 years compared with continuing smokers.\textsuperscript{13} In the NSHD study, a gradient was found for mortality rates according to smoking status at 25 years.*

Table 3 Regression coefficients and 95% confidence intervals for the rate of FEV\textsubscript{1} (ml/year) change between age 43 and 53 years by smoking trajectories, most recent smoking status and smoking status at 25 years*

<table>
<thead>
<tr>
<th>Smoking trajectories (n)</th>
<th>Men (n = 1234)</th>
<th>Women (n = 1306)</th>
<th>All (n = 2540)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never smoker (737)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Predominantly non-smoker (896)</td>
<td>1.20 (−4.80 to 7.19)</td>
<td>1.30 (−3.26 to 5.76)</td>
<td>1.61 (−2.13 to 5.34)</td>
</tr>
<tr>
<td>Predominantly smoker (532)</td>
<td>−8.04 (−14.76 to −1.31)</td>
<td>−6.37 (−11.58 to −1.16)</td>
<td>−6.0 (−10.26 to −1.74)</td>
</tr>
<tr>
<td>Lifelong smoker (375)</td>
<td>−24.8 (−32.25 to −16.91)</td>
<td>−15.44 (−21.20 to −9.68)</td>
<td>−17.61 (−22.34 to −12.84)</td>
</tr>
<tr>
<td>Most recent smoking status (n)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never smoker (737)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Former smoker (909)</td>
<td>−1.56 (−7.50 to 4.38)</td>
<td>−2.51 (−7.15 to 2.12)</td>
<td>0.82 (−4.59 to 2.94)</td>
</tr>
<tr>
<td>Current smoker (894)</td>
<td>−12.91 (−19.16 to −6.66)</td>
<td>−6.13 (−10.53 to 1.73)</td>
<td>−8.44 (−12.21 to −4.68)</td>
</tr>
<tr>
<td>Smoking status at 25 years (n)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never smoker (722)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Former smoker (588)</td>
<td>1.17 (−5.61 to 7.96)</td>
<td>0.39 (−4.57 to 5.35)</td>
<td>0.5 (−3.65 to 4.71)</td>
</tr>
<tr>
<td>Current smoker (839)</td>
<td>−14.32 (−20.44 to −8.20)</td>
<td>−10.1 (−14.72 to 5.48)</td>
<td>−11.0 (−14.86 to −7.21)</td>
</tr>
<tr>
<td>Missing (391)</td>
<td>−6.34 (−13.69 to 1.02)</td>
<td>−23.3 (−8.20 to 3.54)</td>
<td>−3.40 (−8.13 to 1.33)</td>
</tr>
</tbody>
</table>

*Adjusted for FEV\textsubscript{1} level at age 43 years (baseline) and height at age 53 years.
†Negative coefficient refers to a decline in lung function.
\textsuperscript{c}n for sample with complete data.

\textbf{Policy implications}

In considering methodological strategies to assess the effects of smoking behaviours, this study illustrates the benefits of using information from the participant’s lifelong history of smoking.

\textbf{CONCLUSION}

The methodological strategy chosen to measure smoking behaviour has implications for the strength of findings available from a study. From the NSHD, the use of smoking behaviour trajectories has identified markedly stronger adverse effects for all-cause mortality and decline in lung function for lifelong smokers than the results obtained using current smoking status.
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or smoking status at age 25 years. Lifelong smoking behaviours also enabled the detection of differential risks for mortality and decline in lung function between predominantly smokers and predominantly non-smokers. This has highlighted the advantages of forming simplified smoking behaviour classifications by collecting detailed information from former and current smokers about their lifelong history of smoking behaviour.

Contributors: SC conducted the analyses, carried out a preliminary literature review, interpreted the results and revised the paper. GM designed the analyses, interpreted the results, reviewed the literature and wrote the draft. KP contributed to the design of the analysis and the interpretation of results and revised the paper. JK contributed to the design of the analysis, the interpretation of results and edited the paper. DK conceived the study and revised the paper; she will act as guarantor for the paper.

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REFERENCES