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Use of a Microsimulation Method for Assessing Dynamics of Smoking Status and Gains in Life Expectancy after Quitting among U.S. Older Adults

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Appendix: Estimation of Transition Probabilities

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Abstract:

Objectives: Previous studies were unable to estimate the dynamics of smoking status in the U.S. elderly general population, and no study has assessed the benefit of quitting in terms of resultant gains in life expectancy. We proposed a novel method to estimate the percent of quitting in remaining lifetime, successful quitting, and relapse, as well as life expectancy by participants’ baseline smoking status from a large, cohort sample.

Methods: Data were from the Medicare Health Outcome Survey Cohort 15 (baseline 2012, follow-up 2014). We included respondents aged \( \geq 65 \) years (n=164,597). The microsimulation method was used to project individuals’ future smoking status until death through a sequence of independent trials based on multi-state models. Sensitivity analyses were conducted to assess the impact of the model assumptions on estimates.

Results: Among 65-year old daily smokers, 61% would attempt to quit during their remaining lifetime, and 31% would quit successfully. Among 65-year old occasional smokers, 69% would attempt to quit during their remaining lifetime, and 37% would quit successfully. Among 65-year old recent ex-smokers, 53% would relapse. Life expectancy at age 65 years was 20.0 (SE=0.27), 17.2 (SE=0.30), 16.2 (SE=0.29) and 15.9 (SE=0.29) years for long time non-smokers, recent ex-smokers, occasional smokers, and daily smokers, respectively. Although recent ex-smokers had a higher 2-year mortality than current smokers, those who quit up to 77 years (77 for men and 87 years for women) had a significantly longer (p<0.05) life expectancy. Sensitivity analysis demonstrated that the model assumptions had a relatively small impact on estimates with a maximum relative bias less than 7%.

Conclusions: This study provides detailed information regarding the dynamics of smoking status in an understudied and growing population and demonstrates the benefit of smoking cessation on life expectancy. Future research should focus on understanding specific predictors of smoking cessation.

Keywords: smoking cessation, relapse, microsimulation, multistate model
Strengths and limitations of this study

- This study provides detailed information regarding the dynamics of smoking status as well as the benefit of smoking cessation on life expectancy among U.S. older adults.

- The large sample size of this study enables us to obtain estimates, with good reliability, at each of the 2-year age intervals from age 65 years to 95 years.

- This study included extensive sensitivity analyses. Even under the most conservative model assumptions, the impact on our estimates was small, with the maximum relative bias less than 7%.

- Our method assumed only a single transition from baseline to follow-up, and transitions were made at the end of the time interval. This assumption can lead to underestimating percentages of quitting and relapse.

- This analysis did not examine factors (other than age and sex) that affected quitting and relapse or the reasons for quitting and relapse.
Introduction

In the United States, smoking is the leading cause of preventable death. Yet, despite substantial evidence that older persons benefit from quitting smoking in terms of both morbidity and mortality, research on smoking cessation tends to focus on younger adults. Older adults differ from younger adults with regard to smoking prevalence, quit attempts, and relapse. Findings from nationwide surveys of the U.S. general population indicate that the smoking prevalence is lower among older adults than among younger adults. As an example, based on the 2016 National Health Interview Survey (NHIS), 8.8% of persons aged 65 years and older were current smokers compared to 17.1% of persons aged 18 to 64 years. However, compared to younger smokers, older smokers are less likely to attempt quitting in the preceding 12 months.

Previous investigations used data from nationwide, population-based, cross-sectional surveys that relied on retrospective assessments to ascertain dynamics of smoking, such as attempts to quit, successful quitting, and smoking relapse. These assessments were based on the following four questions from the NHIS, the National Health and Nutrition Examination Survey (NHANES), and the Behavioral Risk Factor Surveillance System (BRFSS): (1) “Have you smoked at least 100 cigarettes in your entire life?” (2) “Do you now smoke cigarettes every day, some days, or not at all?” (3) “During the past 12 months, have you stopped smoking for longer than a day because you were trying to quit smoking?” and (4) “How long has it been since you quit smoking cigarettes?” For example, respondents who answered “Yes” to question (3) were classified as having a recent quit attempt. Respondents who answered “Every day” or “Some days” to question (2) and “Yes” to question (3) were classified as having a smoking relapse. Successful quitting was measured by calculating the quit ratio which is the ratio of former smokers, those who answer “Yes” to question (1) and “not at all” to question (2), to ever smokers, those who answer “Yes” to question (1). However, this approach cannot provide estimates of the percent of quitting and successful quitting for current smokers and percent of relapse for ex-smokers because the appropriate denominators for the calculation of percentages cannot be determined. In addition, estimates based on these questions are subject to recall bias as well as selective survival bias.
It is also difficult to quantify the burden of diseases associated with smoking and the benefits of quitting in terms of years of life lost due to smoking and gains in life years after quitting. To our knowledge, no study has estimated gains in life expectancy after quitting in the older U.S. general population. Health risks, in the form of chronic diseases and premature death, may become clinically manifest only after many years of smoking. Similarly, the impact of quitting, in the form of a decrease in mortality, may not be apparent until many years after having quit. Conversely, being in poor health or having chronic conditions usually is the reason to quit smoking, and, therefore, recent ex-smokers might have a higher mortality several years after quitting as compared to current smokers. Additionally, smoking status is not a permanent state and may change throughout the lifespan. A person may attempt to quit and relapse many times. Therefore, estimating life expectancy for individuals based on their baseline smoking status should account for transitions between different smoking statuses during their remaining lifetime.

Ideally, these estimates should be from a large prospective cohort that is representative of the general population and records participants’ smoking status on a regular basis over many decades until death. Due to the high data requirements, we developed a novel method that used a single current smoking status question, Question (2) above, from a large, cohort sample of U.S. elderly population with a relatively short follow-up interval. The present study describes and applies this method to estimate dynamics of smoking status of U.S. older adults aged 65 years or older using a large, national representative legacy dataset. There are two specific aims: (1) to estimate the percentages of quitting during the remaining lifetime and successful quitting among current smokers and the percentages of relapse among recent ex-smokers (defined as less than 2 years of abstinence); and (2) to estimate life expectancy at age 65 to 95 years by respondents’ baseline smoking status. We examined whether life expectancy increased after quitting. Finally, to assess the validity of our estimates, we conducted a sensitivity analysis by examining the impact of the model assumptions on our estimates.

Methods
In this study, the term “quitting” refers to a participant who reported smoking previously and does not currently smoke. “Successful quitting” refers to an ex-smoker who has been abstinent from smoking for at least two years and remains a nonsmoker until death. “Relapse” refers to a person who reported not smoking previously and is smoking now.

**Data and measures:** The data were obtained from the Medicare Health Outcome Survey (HOS), a nationwide survey of Medicare beneficiaries. Each year, the HOS randomly selects a cohort of Medicare beneficiaries who voluntarily enrolled in Medicare Advantage private health plans. The selected individuals who completed a baseline survey are resurveyed two years later. We used the Medicare HOS Cohort 15 whose baseline data were collected in 2012 and follow-up data were collected in 2014. This dataset contains date of death if death occurred by January 31, 2015. We included respondents who were aged 65 years or older and alive at the baseline and participated in the baseline survey. The total sample was 164,597 (Table S1). Among them, 100,290 (61%) were alive at follow-up and completed the follow-up survey, and 64,597 (39%) did not participate in the follow-up survey, including 26,111 (16%) who died and 38,196 (23%) who were alive, but did not complete the survey. An additional 88 participants died after completing the follow-up survey. The average time from the baseline to follow-up survey was 730.3 days (Interquartile range, IRQ=700-730 days). The average follow-up time (from baseline to death or to January 31, 2015) was 901.1 days (IRQ= 932-1,099 days).

The Medicare HOS includes only one question on current smoking status. At both baseline and follow-up surveys, the HOS asks respondents “Do you now smoke every day, some days, or not at all?” We used this question to classify respondents as daily smokers, occasional smokers, and non-smokers. Of the 164,597 individuals who participated the baseline survey, 158,964 (96.6%) answered the smoking question; of the 100,290 individuals who participated the baseline survey, 93,905 (93.6%) answered the smoking question (Table S1).
**Patient and Public Involvement:** This study is a secondary data analysis using the Data from the Medicare Health Outcome Survey by the U.S. Centers for Medicare & Medicaid Services (CMS). There was no formal patient or public involvement in the project design, data collection or analysis.

**Statistical Analysis:** We proposed a smoking transition model that classified non-smokers into recent ex-smokers and longtime non-smokers based on their answers to the current smoking question at the baseline and two years later. The microsimulation method was used to project individuals’ future smoking status until death through a sequence of independent trials based on multi-state models and to estimate their expected number of remaining life years (i.e., life expectancy).18,19

Multi-state models were used to estimate probabilities of transferring between different smoking states15,19 Because the baseline and follow-up surveys were 2 years apart, we constructed a multi-state model in 2-year age intervals, at ages 65, 67, … years. To illustrate the method, we describe a Markov process with \( k \) transient states \( (s_1, s_2, \ldots, s_k) \) for \( k \) levels of smoking status and one absorbing state \( (s_{k+1}) \) for dead. Let \( p_t^{ij} = \Pr (s_{t+2} = j | s_t = i) \) be the transition probability from state \( s_i \) at age \( t \) to state \( s_j \) at age \( t + 2 \). These transition probabilities satisfy linear dependence: \( \sum_{j=1}^{k+1} p_t^{ij} = 1 \) for all \( i \). Because \( s_{k+1} \) is the absorbing state, \( p_t^{k+1,i} = 0 \) for \( i \leq k \) and \( p_t^{k+1,k+1} = 1 \).

Using the current smoking status question, we applied a multi-state model with 3 transient states, \( s_1, s_2, s_3 \) for “smoking daily”, “smoking occasionally”, and “non-smoking”, and one absorbing state \( (s_4) \) for dead (Figure 1, Model A). This model has a transition matrix

\[
P_x = \begin{bmatrix}
p_1^{1,1} & p_1^{1,2} & p_1^{1,3} & p_1^{1,4} \\
p_2^{2,1} & p_2^{2,2} & p_2^{2,3} & p_2^{2,4} \\
p_3^{3,1} & p_3^{3,2} & p_3^{3,3} & p_3^{3,4} \\
0 & 0 & 0 & 1
\end{bmatrix}.
\]
In Model A, the “non-smoking” state includes recent ex-smokers, longtime ex-smokers, and never smokers. This model assumes the same relapse and mortality rates for them. Although recent ex-smokers compose a very small proportion of the “non-smoking” group, nearly all relapses are from those with less than 2 years of abstinence.20-22 Also, recent ex-smokers might have a higher mortality rate than longtime ex-smokers and never smokers. Therefore, Model A may be invalid.

To solve this problem, we partitioned the “non-smoking” state, \( s_3 \), into two mutually exclusive states: \( s_{3A} \) for “recent non-smoking” and \( s_{3B} \) for “longtime non-smoking” (Figure 1, Model B). Because never smokers and longtime ex-smokers would be unlikely to start smoking at an advanced age of 65 years or older and nearly all relapses (about 99%) were within 2 years of abstinence,21-24 we assumed all relapses occurred within 2 years of abstinence and older longtime non-smokers do not initiate smoking or experience relapse, i.e., \( p_{t}^{3B,1} = p_{t}^{3B,2} = 0 \). Based on this assumption, Model B has a transition probability matrix

\[
P_x = \begin{pmatrix}
p_{1,1}^{1} & p_{1,2}^{1} & p_{1,3A}^{1} & 0 & p_{1,4}^{1} \\
p_{2,1}^{2} & p_{2,2}^{2} & p_{2,3A}^{2} & 0 & p_{2,4}^{2} \\
p_{3A,1}^{3A} & p_{3A,2}^{3A} & 0 & p_{3A,3B}^{3A} & p_{3A,4}^{3A} \\
0 & 0 & 0 & 0 & 1
\end{pmatrix}
\]

For Model B, the recent non-smoking measure was operationalized as smoking at baseline and not smoking at follow-up. The longtime non-smoking measure was operationalized as not smoking at both baseline and follow-up.

All transition probabilities (\( p_{t}^{ij}, i = 1,2,3, \) and \( j = 1,2,3,4 \)) in Model A at a given age between states \( s_1, s_2, s_3 \) and \( s_4 \) can be estimated from the HOS data15 (details are in Appendix A1). For Model B, six transition probabilities (\( p_{t}^{1,1}, p_{t}^{1,2}, p_{t}^{1,4}, p_{t}^{2,1}, p_{t}^{2,2}, \) and \( p_{t}^{2,4} \)) are available from Model A directly. The remaining eight transition probabilities, \( p_{t}^{1,3A}, p_{t}^{2,3A}, p_{t}^{3A,1}, p_{t}^{3A,2}, p_{t}^{3A,3B}, p_{t}^{3B,3B}, p_{t}^{3A,4}, \) and \( p_{t}^{3B,4} \), can be estimated based on assumptions of Model B (details are in Appendix A2).
Microsimulations: We projected the future smoking status of each individual in a synthetic cohort of persons using the microsimulation method.\textsuperscript{18,19} For an age cohort of 1,000,000 individuals of a given initial state $s_i$ ($i = 1, 2, 3A, 3B$) at starting age $x$, using the estimated transition probabilities of Model B, we simulated each individual’s smoking state at age $x + 2$, $x + 4$, ... iteratively until all individuals died. Percent of quitting in the remaining lifetime was estimated as the proportion ever entering the recent non-smoking state ($s_{3A}$) for a cohort of current smokers ($s_1$ or $s_2$) at the starting age $x$. Percent of successful quitting was estimated as the proportion entering the longtime non-smoking state ($s_{3B}$) for a cohort of current smokers. Percent of relapse was estimated as the proportion entering the current smoking states ($s_1$ or $s_2$) for a cohort of recent ex-smokers ($s_{3A}$).

Life expectancy is estimated as the average number of years from the starting age to age of death for a cohort of individuals in a given initial state $s_i$ ($i = 1, 2, 3A, 3B$) at starting age $x$. If death occurred during the age interval from $x + 2k$ to $x + 2(k + 1)$, average years to death is $e_x = 2k + 2a$, where $a$ is the proportion of time lived in the 2-year age interval for persons who died during the interval. Assuming a constant mortality rate during an age interval, it can be shown that $a = 1 - \frac{1}{\ln(1 - P)} - \frac{1}{P}$, where $P = P_{i,4}$ ($i = 1, 2, 3A, 3B$) is probability of death during the age interval. When $P$ is small and close to 0, $a \approx 0.5$, otherwise, $a < 0.5$.

The standard errors of all estimates were derived from microsimulation and includes the random variation of individuals’ outcomes conditional to transition probabilities and imprecision of the estimated transition probabilities (i.e., first and second order Monte Carlo uncertainty).\textsuperscript{19,25}

Sensitivity Analysis: Our estimates relied on the assumption that all relapses occurred within 2 years of abstinence and no relapse for longtime non-smokers. This assumption may lead to underestimation of successful quitting. To assess the impact of this assumption, we conducted a sensitivity analysis by examining a model that allows relapse for non-smokers who had not smoked in the past 2+ years (Figure 1, Model C). Because relapse rates decreased with years of abstinence,\textsuperscript{5,23,24,26} we assumed that all relapses for those who had not smoked in
the past 2+ years occurred between years 2 and 4 of abstinence and there was no relapse after 4+ years of abstinence. Extending from Model B, and let states $s_{3A}$, $s_{3B1}$, and $s_{3B2}$ be non-smoking for < 2 years, 2-4 years, and ≥ 4 years, respectively, the Model C has a transition matrix

$$
P_x = \begin{bmatrix}
    p^{1.1} & p^{1.2} & p^{1.3A} & 0 & 0 & p^{1.4} \\
    p^{2.1} & p^{2.2} & p^{2.3A} & 0 & 0 & p^{2.4} \\
    p^{3A.1} & p^{3A.2} & 0 & p^{3A.3B1} & 0 & p^{3A.4} \\
    p^{3B1.1} & p^{3B1.2} & 0 & 0 & p^{3B1.3B2} & p^{3B1.4} \\
    0 & 0 & 0 & 0 & p^{3B2.3B2} & p^{3B2.4} \\
    0 & 0 & 0 & 0 & 0 & 1 
\end{bmatrix}.
$$

To estimate transition probabilities of Model C, we made following two assumptions:

1. We assumed the probabilities of transferring from state $s_{3B1}$ to states $s_1$ and $s_2$ are in the form of $p^{3B1.1} = RR \times p^{3A.1}$ and $p^{3B1.2} = RR \times p^{3A.2}$, respectively, where RR is the risk ratio of relapse for state $s_{3B1}$ relative to state $s_{3A}$. Data from previous studies showed that the relapse rate for those with 2+ years of abstinence was between 5% and 13% of that for those with ≤ 2 years of abstinence.\textsuperscript{21-24,26} We used RR=0.05 and 0.15 as lower bound and upper bound, respectively.

2. We expected that the mortality rates for those who had quit for between 2-4 years should be between the mortality rates for those who had quit for > 4 years and those who quit ≤ 2 years of the same age,\textsuperscript{10} i.e., $p^{3A.4} \geq p^{3B1.4} \geq p^{3B2.4}$. We used $p^{3B1.4} = p^{3B1.4}$ and $p^{3B1.4} = p^{3A.4}$ as lower bound and upper bound, respectively.

Nine transition probabilities ($p^{1.1}, p^{1.2}, p^{1.3A}, p^{1.4}, p^{2.1}, p^{2.2}, p^{2.3A}, p^{2.4}$, and $p^{3A.4}$) are from Model B directly. The remaining nine transition probabilities ($p^{3A.1}, p^{3A.2}, p^{3A.3B1}, p^{3B1.1}, p^{3B1.2}, p^{3B1.3B2}, p^{3B1.4}, p^{3B2.3B2}$, and $p^{3B2.4}$) can be estimated based on Model C assumptions. Details of transition probability estimation for Model C are available in Appendix A3. We compared estimates from Model B to that from Model C.
Results

At baseline, the average participant age was 75.1 years, with 53% of participants between 65 and 74 years old, 34% of participants between 75 and 84 years old, and 13% of participants 85 years or older (Table S1). Women comprised 58% of the sample, and white, non-Hispanics 76% of the sample. About 10% participants reported currently smoking, including 6.6% daily smokers and 3.1% occasional smokers. At the follow-up survey, about 8% participants reported currently smoking, including 5.2% daily smokers and 2.7% occasional smokers. Men were more likely (about 25% more) to be current smokers than women.

Table 1 presents the estimated transition probabilities for each the four smoking statuses: smoking every day, smoking some days, recent non-smoking, and longtime non-smoking. These results provide 2-year quit rates for current smokers and 2-year relapse rates for recent quitters. As an example, for 65-year old daily smokers, 83.1% (73.0% daily and 10.1% occasionally) would still smoke at age 67 and 12.2% would quit; as a comparison, for a cohort of 65-year old occasional smokers, at age 67 years, 75.7% (16.5% daily and 59.2% occasionally) would still smoke and 19.4% would quit. For 65-year old recent ex-smokers, at age 67 years, 53.2% (18.4% daily and 34.8% occasionally) would smoke again (relapse), and 40.5% would still abstain from smoking. These results also provide 2-year mortality by smoking status. Recent ex-smokers had the highest 2-year mortality rates, followed by daily smokers and occasional smokers, and longtime non-smokers had the lowest 2-year mortality rates. For example, the 2-year mortality rates among 65-year-old persons were 6.3%, 4.8%, 5.0%, and 2.0% for the four groups, respectively.

| Age (x) | Transfer from $s_1$ to | | | | | Transfer from $s_2$ to |
|----|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| | $s_1$ | $s_2$ | $s_3_A$ | $s_3_B$ | $s_4$ | $s_1$ | $s_2$ | $s_3_A$ | $s_3_B$ | $s_4$ |
| 65 | 73.0% | 10.1% | 12.2% | 0% | 4.8% | 16.5% | 59.2% | 19.4% | 0% | 5.0% |
| 67 | 71.6% | 9.8% | 12.6% | 0% | 6.0% | 16.4% | 57.2% | 20.9% | 0% | 5.4% |
| 69 | 70.2% | 9.7% | 12.8% | 0% | 7.4% | 16.3% | 55.8% | 21.8% | 0% | 6.1% |
| 71 | 68.5% | 9.8% | 12.6% | 0% | 9.0% | 16.2% | 54.7% | 22.1% | 0% | 7.1% |
| 73 | 66.8% | 10.1% | 12.3% | 0% | 10.8% | 16.0% | 53.8% | 22.0% | 0% | 8.2% |
Table 1: Transfer of smoking status between years 2015 and 2017

| Year | Smoking Status | 2015 | 2016 |
|------|----------------|------|------|
| 2015 | Smoking        | 50%  | 40%  |
| 2016 | Non-smoking    | 30%  | 50%  |

Legend: Smoking every day, non-smoking, recent ex-smoker, long-term ex-smoker

Figure 2 presents percentages of quitting in the remaining lifetime and successful quitting for current smokers, respectively, and percentages of relapse for recent ex-smokers. Standard errors of estimates are available in Table S2. For example, among 65-year old daily smokers, 61.3% (SE=1.5%) would quit in their remaining lifetime, and 31.5% (SE=1.5%) would quit successfully. Among 65-year old recent ex-smokers, 53.2% (SE=1.6%) would relapse. Although the percentages of quitting in the remaining lifetime were similar...
between men and women (Table S3), women were more likely to quit smoking successfully and less likely to relapse than men.

Life expectancy at a given age by participants’ baseline smoking status are in Table 2, with standard errors in Table S4. For example, life expectancy at age 65 years was 20.0 (SE=0.27), 17.2 (SE=0.30), 16.2 (SE=0.29) and 15.9 (SE=0.29) years for longtime non-smokers, recent ex-smokers, occasional smokers, and daily smokers, respectively. Quitting between 65 and 77 years of age had a significantly (p<0.05) longer life expectancy as compared to current smokers. All non-smokers had a significantly longer life expectancy than did all current smokers between the ages of 65 to 87 years. When examined by sex (Table S5), the difference in life expectancy between non-smokers and smokers was similar between men and women. However, quitting smoking contributed to slightly greater gains in life expectancy among women than men. Men benefit from quitting up to age 77 years, while women benefit from quitting up to age 87 years.

Table 2: Life Expectancy by Baseline Smoking Status at Ages 65-95 Years

| Age (x) | Smoking | Not smoking at all | Quitting vs. not quitting | Non-smokers vs. smokers |
|---------|---------|--------------------|---------------------------|-------------------------|
|         | Every day | Some days | All smokers | Recent | Long time | All non-smokers | 3 | 4 |
| 65      | 15.9 | 16.2 | 16.0 | 17.2 | 20.0 | 19.9 | 1.2* | 3.9* |
| 67      | 14.4 | 14.9 | 14.6 | 16.0 | 18.4 | 18.3 | 1.4* | 3.8* |
| 69      | 13.0 | 13.6 | 13.2 | 14.6 | 16.8 | 16.8 | 1.5* | 3.6* |
| 71      | 11.7 | 12.3 | 11.9 | 13.2 | 15.3 | 15.3 | 1.4* | 3.4* |
| 73      | 10.5 | 11.1 | 10.7 | 11.8 | 13.8 | 13.8 | 1.2* | 3.1* |
| 75      | 9.4  | 10.0 | 9.6  | 10.5 | 12.5 | 12.4 | 0.9* | 2.8* |
| 77      | 8.4  | 8.9  | 8.6  | 9.2  | 11.1 | 11.1 | 0.6* | 2.5* |
| 79      | 7.6  | 8.0  | 7.7  | 8.1  | 9.9  | 9.8  | 0.4  | 2.1* |
| 81      | 6.8  | 7.2  | 6.9  | 7.1  | 8.7  | 8.7  | 0.1  | 1.7* |
| 83      | 6.2  | 6.4  | 6.2  | 6.2  | 7.6  | 7.6  | 0.0  | 1.4* |
| 85      | 5.6  | 5.7  | 5.6  | 5.5  | 6.6  | 6.6  | -0.1 | 1.0* |
| 87      | 5.0  | 5.1  | 5.1  | 5.0  | 5.7  | 5.7  | -0.1 | 0.7  |
| 89      | 4.6  | 4.6  | 4.6  | 4.5  | 5.0  | 5.0  | -0.1 | 0.4  |
| 91      | 4.1  | 4.1  | 4.1  | 4.2  | 4.3  | 4.3  | 0.1  | 0.2  |
| 93      | 3.7  | 3.7  | 3.7  | 3.7  | 3.7  | 3.7  | 0.1  | 0.0  |
| 95      | 3.3  | 3.3  | 3.3  | 3.3  | 3.2  | 3.2  | 0.0  | -0.1 |
1: quit less than 2 years
2: never smoke or quit > 2 years
3: difference between recent non-smokers and all smokers
4: difference between all non-smokers and all smokers
*: p < 0.05 for testing for difference between 2 groups.

**Sensitivity Analysis Results:** Finally, we examined the impact of the model assumption (no relapse among longtime non-smokers) on our estimates by comparing estimates from Model B to estimates from Model C which allows relapse for non-smokers with 2+ years’ abstinence (Table 3). The model assumption had no or a very small impact on estimation of percent of quitting in the remaining lifetime, percent of relapse, and life expectancy for longtime non-smokers, as demonstrated by the similar estimates from Model B and Model C. Under the various model assumptions, the model assumption underestimated percent of successful quitting slightly, as estimates from Model B were about 0.8% to 2.7% lower than that from Model C, with relative bias from -2.2% to -6.0%; and overestimated life expectancy slightly for current smokers and recent ex-smokers, as estimates from Model B were about 0.1-1.0 years higher than that from Model C, with relative bias from 0.4% to 5.9%.
Table 3: Sensitivity Analysis – Assess the Validity of Model Assumption

| Outcomes                      | Model B | Model C RR=0.05 | Model C RR=0.15 | Bias RR=0.05 | Bias RR=0.15 | Relative bias RR=0.05 | Relative bias RR=0.15 |
|-------------------------------|---------|-----------------|-----------------|--------------|--------------|-----------------------|-----------------------|
| Quitting                      |         |                 |                 |              |              |                       |                       |
| smoked every day              | 61.3%   | 61.2%           | 61.2%           | 0.0%         | 0.0%         | 0.1%                  | 0.1%                  |
| smoked some days              | 68.6%   | 68.6%           | 68.5%           | 0.0%         | 0.0%         | 0.0%                  | 0.0%                  |
| Successful quitting           |         |                 |                 |              |              |                       |                       |
| smoked every day              | 31.5%   | 32.2%           | 32.2%           | -0.8%        | -0.7%        | -2.2%                 | -2.2%                 |
| smoked some days              | 36.8%   | 37.6%           | 39.2%           | -0.8%        | -0.8%        | -2.4%                 | -2.4%                 |
| Relapse                       | 53.2%   | 53.1%           | 52.9%           | 0.1%         | 0.1%         | 0.3%                  | 0.3%                  |
| Life expectancy               |         |                 |                 |              |              |                       |                       |
| smoked every day              | 15.9%   | 15.8%           | 15.4%           | 0.1%         | 0.2%         | 0.5%                  | 3.1%                  |
| smoked some days              | 16.2%   | 16.2%           | 16.0%           | 0.1%         | 0.2%         | 0.6%                  | 3.6%                  |
| recent ex-smokers             | 17.2%   | 17.1%           | 16.3%           | 0.2%         | 0.4%         | 0.5%                  | 2.8%                  |
| Longtime nonsmokers           | 20.0%   | 20.0%           | 20.0%           | 0.0%         | 0.0%         | 0.0%                  | 0.2%                  |

1: all estimates are at age 65 years
2: quit less than 2 years
3: never smoke or quit ≥ 2 years
Discussion

This study provides detailed information regarding the dynamics of smoking status as well as the benefit of smoking cessation on life expectancy among U.S. older adults. Not surprisingly, we found that smoking was associated with a significantly reduced life expectancy and that gains in life expectancy could be achieved with quitting up to age 77 years (up to 77 years for men, and up to 87 years for women). Yet, in terms of quitting, although approximately two thirds of 65-year-old smokers will attempt to quit smoking during their remaining lifetime, only about one third will be able to quit successfully, while about one in every two 65-year-old recent ex-smokers will relapse.

As the age pyramid for the U.S. shifts, due to a greater proportion of persons aged 65 and older, and life expectancy increases, investigators have sought to characterize the range of health trajectories among the elderly. Because of the trend of an increasing percentage of persons 65 and over in the U.S. population, the total number of elderly persons who smoke may increase even if the prevalence of smokers is unchanged. Understanding the age differences in cessation and relapse rates as well as benefit of quitting is critical, given that smoking patterns and predictors may differ between younger and older populations. According to 2017 NHIS data, recent successful cessation tends to decrease with age and is lowest among adults 65 and older. The elderly population represent a heterogeneous group, and the dynamics of smoking may differ between young-old (65-74), middle-old (75-84), and old-old (85 and over). The large sample size of the Medicare HOS data enables us to obtain estimates, with good reliability, at each of the 2-year age intervals from age 65 years to 95 years, and this is one of strengths of our study.

Many previous investigations of smoking cessation and relapse in the U.S. general population relied on questions of previous quitting attempts and years since quitting from large, nationwide, cross-sectional surveys such as the NHIS, NHANES, and BRFSS. The main weakness of this approach is the inability to calculate percent of successful quitting and relapse as well as potential recall bias and selective survival bias. Although some studies used cohort data to analyze the dynamics of smoking, the sample sizes of these studies were
usually too small to provide reliable estimates. Furthermore, these cohort studies used either clinical samples or non-representative samples of the general population. We proposed a method based on the microsimulation method that constructs a synthetic cohort of participants with the same baseline smoking status by simulating each individual’s future smoking status until death. This method is novel through using a single current smoking question contained in a large, cohort survey of the U.S. general elderly population with a relatively short follow-up. In this study, the smoking status is assessed and the probabilities of changing smoking status were assessed at two time points. The respondents’ previous smoking status was obtained by modeling transition probabilities between different smoking status from baseline and follow-up surveys. We simulated respondents’ future smoking status through a sequence of independent trials based on transition probabilities between different smoking states from multi-state models.

All transition probabilities can be estimated by assuming no smoking relapse or initiation for longtime non-smokers, which includes never smokers and former smokers who quit smoking for more than 2 years. We made this assumption based on: (1) Nearly half of older adults had never smoked before and they were very unlikely to start smoking for the first time. The smoking initiation rate decreased with age after 18 years of age. Data from the 2003-2010 the NHANES indicate that among ever smokers aged 65 years or older, only 0.1% started smoking at age 65 years or later. (2) Relapse rates would be much lower after 2+ years of abstinence. Previous studies uniformly showed that relapse rates decreased with years of abstinence. For example, data from 1,449 former smokers in California showed that the likelihood of relapse for those with 2+ years of abstinence was about 93% lower than that for those with less than 2 years of abstinence. Additionally, our sensitivity analysis demonstrated that, even using the most conservative estimation, the impact on our estimates was small, with the maximum relative bias less than 7%.

This a study has a number of limitations. First, because this analysis is based on a survey of Medicare beneficiaries who voluntarily enrolled in private Medicare Advantage health plans, the current sample may be younger and healthier than the overall Medicare population.
smoking status, and the difference between “smoke some days” and “not smoke at all” in question “Do you now smoke?” is not very clear. Third, we assumed only a single transition from baseline to follow-up, and transitions were made at the end of the time interval. This assumption can lead to underestimating percentages of quitting and relapse. Fourth, our analysis did not examine factors (other than age and sex) that affected quitting and relapse or the reasons for quitting and relapse.

This study estimated smoking patterns (quitting and relapse) and the benefit of quitting in a traditionally overlooked demographic subgroup. These estimates are currently unavailable for the U.S. general population of older adults and would enable an understanding of the trajectory and impact of tobacco use. Such information also would help guide the investment of smoking cessation services as the population ages. Future data collection should include a respondent’s number of prior quit attempts and times advised to quit smoking, given that both will influence quit rates and, ultimately, guide resource allocation and risk messaging. Additionally, further investigations should aim to develop a broader understanding of smoking cessation predictors to identify specific strategies that might work best for the elderly based on specific sociodemographic features or chronic conditions.
Data availability statement: This study is a secondary data analysis using the Limited Data Set (LDS) of the HOS from the U.S. Centers for Medicare & Medicaid Services (CMS). The dataset contains potentially identifying or sensitive patient information (e.g., participants’ zip code, date of birth, date of death, etc.). A signed Data Use Agreement (DUA) with CMS is required to obtain LDS data files (https://www.cms.gov/Research-Statistics-Data-and-Systems/Files-for-Order/LimitedDataSets/HOS ). In order to request a LDS files, investigators must follow the instructions on this link: https://www.cms.gov/Research-Statistics-Data-and-Systems/Files-for-Order/Data-Disclosures-Data-Agreements/EPPEpilot-LDSS.

Ethical approval statement: The study was reviewed and approved by the Columbia University Medical Center institutional review board (IRB-AAAR4154).

Patient and public involvement: Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Contributors: HJ was in charge of the conceptualization, methodology, software, validation, and data curation. Both authors (HJ and EIL) Lubetkin were involved in the writing, editing, and visualization; both authors read and approved the final manuscript.

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Appendix: Estimation of Transition Probabilities

A1. Estimation for Model A: Individuals with missing smoking status at both baseline and follow-up surveys were excluded from all analyses. Individuals who did not participate the follow-up survey and individuals with missing smoking status at one of the two surveys were included in estimation of probability of death only and were excluded from the estimation of transition between different smoking statuses.

For Model A, all transition probabilities \( p_{ij}^{t} \) from age \( t \) to \( t + 2 \) (\( t = 65, 67, \ldots \)) between three smoking states \( (s_1, s_2, s_3) \) were obtained by estimating instantaneous transition rates at age \( t \), \( \mu_{ij}^{t} = \lim_{\Delta \to 0} \frac{\Pr(s_{t+\Delta} = j | s_t = i)}{\Delta} \), from a log-linear model with age (as a cubic polynomial function) as a time-dependent predictor. Assuming a constant instantaneous transition rate in an age interval, we obtained transition probability as \( p_{ij}^{t} = 1 - \exp(-2\mu_{ij}^{t}).^{15,19} \)

The probability of death \( p_{i}^{t+2} \) for smoking state \( s_i \) (\( i = 1, 2, 3 \)) during age interval \( t \) to \( t + 2 \) was estimated based on the probability of death for the total population and hazard ratio of death for each state relative to the reference group ("not smoking") at different ages. Using data estimated from the 2012 U.S. life tables, let \( p_t \) be probability of death, and \( l_{ix} \) be number of persons surviving to age \( t \) in state \( s_i \), and \( l_t \) be number of persons surviving to age \( t \). Using an estimation from a Cox proportional hazard model with age as a time-varying covariate from the HOS data, let \( h_t^i \) (\( i = 1, 2 \)) be the hazard ratio of death for state \( s = (s_2, s_3) \) relative to the reference state \( s_1 \) at age \( t \). Assuming a constant risk of death during each age interval, we estimated \( p_{i}^{t+2}(i = 1, 2, 3) \) by solving the following nonlinear equations numerically: \(^{15}\)

\[
\sum_{i=1}^{3} l_{ix} p_{i}^{t+2} = l_{i} p_t
\]

\[
p_{i}^{t+1} = 1 - \left(1 - p_{i}^{t+1}\right)^{h_t^i}, \quad i = 1, 2.
\]
**A2. Estimation for Model B:** Six transition probabilities \((p_{1,1}^1, p_{1,2}^1, p_{1,4}^1, p_{2,1}^2, p_{2,2}^2, \text{ and } p_{2,4}^2)\) are from Model A directly. To estimate remaining eight transition probabilities: \(p_{1,3}^1, p_{2,3}^1, p_{3,1}^2, p_{3,3}^2, p_{3,3}^1, p_{3,4}^4\), and \(p_{3B,3B}^3\), let \(w\) be the proportion in state \(s_{3A}\) among total non-smoking states (i.e., in \(s_{3A}\) or \(s_{3B}\)). We estimated proportions in state \(s_{3A}\) and state \(s_{3B}\) among the total population at age \(t\) from logistic models and obtained \(w\) from these two proportions as \(w = \frac{\Pr(s_{3A} = 1)}{\Pr(s_{3B} = 1) + \Pr(s_{3A} = 1)}\). Let \(HR_{3A:3B}\) be the hazard ratio of death for state \(s_{3A}\) relative to state \(s_{3B}\), and \(HR_{3A:3B, t}\) at age \(t\) were estimated from a Cox proportional hazard model with age as a time-varying covariate from the HOS data.\(^{15}\)

Given that \(p_{1,3}^1, p_{2,3}^1, p_{3,2}^1, p_{3,3}^1, p_{3,4}^4, w\), and \(HR_{3A:3B}\) were known, we can obtain these eight unknowns by solving following eight equations:

\[
\begin{align*}
(1) & \quad p_{1,3}^1 \text{(Model B)} = p_{1,3}^1 \text{(Model A)}; \\
(2) & \quad p_{2,3}^1 \text{(Model B)} = p_{2,3}^1 \text{(Model A)}; \\
(3) & \quad w p_{3,1}^1 \text{(Model B)} = p_{3,1}^1 \text{(Model A)}; \\
(4) & \quad w p_{3,2}^2 \text{(Model B)} = p_{3,2}^2 \text{(Model A)}; \\
(5) & \quad p_{3B,3B}^3 + p_{3B,4}^3 = 1; \\
(6) & \quad w p_{3A,3B}^3 + (1 - w)p_{3B,3B}^3 \text{(Model B)} = p_{3,3}^3 \text{(Model A)}; \\
(7) & \quad w p_{3A,4}^4 + (1 - w)p_{3B,4}^3 \text{(Model B)} = p_{3,4}^4 \text{(Model A)}; \\
(8) & \quad p_{3A,4}^3 = 1 - (1 - p_{3B,4}^3)^{HR_{3A:3B}}. 
\end{align*}
\]

Equations (1) and (2) are based on the number of (daily and occasional) smokers who become nonsmokers in Model B which equals that in Model A; (3) and (4) are based on recent nonsmokers who become smokers in Model B which is equal to the nonsmokers who become smokers in Model A; (5) is based on linear dependence, \(\sum_{j=1}^{k+1} p_{t,j}^{ij} = 1\) for \(i = 3B\); (6) is based on the number of nonsmokers (both recent and longtime) who become longtime nonsmokers in Model B being equal to the number of nonsmokers who remain nonsmokers in Model A; (7) is based on the number of deaths for nonsmokers (recent and longtime) in Model B being equal to the...
number of deaths for nonsmokers in Model A; and (8) is based on the relationship between the probability of death for recent nonsmokers and longtime nonsmokers.

Solutions for \( p_{1,3A} \), \( p_{2,3A} \), \( p_{3A,1} \), and \( p_{3A,2} \) can be obtained directly from equations (1)-(4), while solutions for \( p_{3A,3B} \), \( p_{3B,3B} \), \( p_{3A,4} \), and \( p_{3B,4} \) are obtained by solving nonlinear equations (5)-(8) numerically.

### A3. Estimation for Model C:

Nine transition probabilities \( (p_{1,1}, p_{1,2}, p_{1,3A}, p_{1,4}, p_{2,1}, p_{2,2}, p_{2,3A}, p_{2,4}, \text{and } p_{3A,4}) \) are from Model B directly. The remaining nine transition probabilities: \( p_{3A,3B}, p_{3A,4}, p_{3B,3B}, \text{and } p_{3B,4} \), can be estimated using the similar method described in A.2. Let \( w_1 = \frac{\text{Pr}(s_{3A} = 1)}{\text{Pr}(s_{3A} = 1) + \text{Pr}(s_{3B1} = 1)} \) and \( w_2 = \frac{\text{Pr}(s_{3B1} = 1)}{\text{Pr}(s_{3A} = 1) + \text{Pr}(s_{3B2} = 1)} \). Because \( \text{Pr}(s_{3B} = 1) \) and \( \text{Pr}(s_{3A} = 1) \) are available from Model B (see Appendix A.2) \( \text{Pr}(s_{3B1} = 1) + \text{Pr}(s_{3B2} = 1) = \text{Pr}(s_{3B} = 1) \), we just need to estimate \( \text{Pr}(s_{3B1} = 1) \) in order to obtain \( w_1 \) and \( w_2 \). Let \( l_x^1 \) be number of persons in state \( s_i \) at age \( x \). Based on Model C definition, the number of persons in state \( s_{3B1} \) at age \( x \) equals the number of persons in state \( s_{3A} \) at age \( x - 2 \) minus the number of persons who died between age \( x - 2 \) and \( x \), i.e., \( l_x^{3B1} = l_x^{3A}(1 - p_{x-2}^{3A4} - p_{x-2}^{3A1} - p_{x-2}^{3A2}) \). We can obtain \( \text{Pr}(s_{3B1} = 1) \) using this equation.

Given that \( w_1 \) and \( w_2 \) are known, we can obtain the remaining ten unknowns by solving the following nine equations numerically:

1. \( p_{3B1,1}^{3} = RR \cdot p_{3A1}^{3} \)
2. \( p_{3B1,2}^{3} = RR \cdot p_{3A2}^{3} \)
3. \( p_{3B1,4}^{3} = p_{3B24} \) or \( p_{3B1,4}^{3} = p_{3A4} \)
4. \( w_1 p_{3A1}^{3} + (1 - w_1) p_{3B1,1}^{3} \text{ (Model C) } = p_{3A,1}^{3} \text{ (Model B) } \)
5. \( w_1 p_{3A2}^{3} + (1 - w_1) p_{3B1,2}^{3} \text{ (Model C) } = p_{3A,2}^{3} \text{ (Model B) } \)
6. \( p_{3A3B}^{3} \text{ (Model C) } = p_{3A3B}^{3} \text{ (Model B) } \)
7. \( w_2 p_{3B1,3B}^{3} + (1 - w_2) p_{3B2,3B}^{3} \text{ (Model C) } = p_{3B,3B}^{3} \text{ (Model B) } \)
8. \( w_2 p_{3B1,4}^{3} + (1 - w_2) p_{3B2,4}^{3} \text{ (Model C) } = p_{3B,4}^{3} \text{ (Model B) } \)
9. \( p_{3B2,3B}^{3} + p_{3B2,4}^{3} = 1 \)

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Equations (1) and (2) are Model C assumption 1. We used $RR = 0.05$ or $0.15$ for lower and upper bound, respectively; (3) is Model C assumption 2. We used $p^{3B_1,4} = p^{3B_2,4}$ or $p^{3B_1,4} = p^{3A_4}$ for lower and upper bound, respectively; (4) and (5) are based on the number of nonsmokers (both 3A and 3B1) who become (daily and occasional) smokers in Model C being equal to the number of recent nonsmokers (3A) who become smokers in Model B; (6) is based on the number of recent quitters (3A) who become longtime nonsmokers (2-4 years abstinence, 3B1) in Model C being equal to the number of recent quitters becoming longtime nonsmokers (3B) in Model B; (7) is based on the number of total longtime smokers (3B1 and 3B2) who remain longtime nonsmokers (3B2 only) in Model C being equal to the number of longtime smokers (3B) who remain longtime nonsmokers (3B) in Model B; (8) is based on the number of deaths for total longtime nonsmokers (3B1 and 3B2) in Model C being equal to the number of deaths for longtime nonsmokers (3B) in Model B; and (9) is based on the linear dependence, $\sum_{j=1}^{k+1} p_{i,j}^{k+1} = 1$ for $i = 3B2$. 
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Figure 1: Transition Models of Smoking Status.

Figure 2: Percent of Quitting in Remaining Lifetime, Successful Quitting, and Relapse by Age
Figure 1

215x279mm (300 x 300 DPI)
Figure 2

215x279mm (300 x 300 DPI)
## Supplementary Tables

### Table S1: Sample Characteristics at Baseline and Follow-up

|                         | Baseline N | Baseline Percent | Follow-up N | Follow-up Percent |
|-------------------------|------------|------------------|-------------|------------------|
| Total sample            | 164,597    | 100%             | 100,290     | 100%             |
| Age, Mean (SD)          | 75.1 (7.4) |                  | 76.2 (6.7)  |                  |
| 65-74                   | 87,972     | 53.4%            | 47,929      | 47.8%            |
| 75-84                   | 55,676     | 33.8%            | 39,337      | 39.2%            |
| 85-94                   | 19,313     | 11.7%            | 12,308      | 12.3%            |
| 95+                     | 1,636      | 1.0%             | 716         | 0.7%             |
| Female                  | 95,115     | 57.8%            | 58,519      | 58.4%            |
| Race/ethnicity          |            |                  |             |                  |
| White non-Hispanics     | 121,334    | 76.1%            | 77,694      | 78.2%            |
| Black non-Hispanics     | 13,031     | 8.2%             | 7,427       | 7.5%             |
| Hispanics               | 15,735     | 9.9%             | 8,803       | 8.9%             |
| Other                   | 9,404      | 5.9%             | 5,408       | 5.4%             |
| Do you now smoke        |            |                  |             |                  |
| Every day               | 10,448     | 6.6%             | 4,883       | 5.2%             |
| Some days               | 5,004      | 3.1%             | 2,524       | 2.7%             |
| Not at all              | 143,512    | 90.3%            | 86,498      | 92.1%            |
| Smoking status by Sex   |            |                  |             |                  |
| Men                     |            |                  |             |                  |
| Smoke every day         | 5,118      | 7.6%             | 2,274       | 5.8%             |
| Smoke some days         | 2,270      | 3.4%             | 1,205       | 3.1%             |
| Not smoke at all        | 59,671     | 89.0%            | 35,636      | 91.1%            |
| Women                   |            |                  |             |                  |
| Smoke every day         | 5,330      | 5.8%             | 2,609       | 4.8%             |
| Smoke some days         | 2,734      | 3.0%             | 1,319       | 2.4%             |
| Not smoke at all        | 83,841     | 91.2%            | 50,862      | 92.8%            |
Table S2: Standard Error of Estimates in Figure 2

| Age (x) | Percent quitting | Percent successful quitting | Percent Relapse |
|---------|------------------|-----------------------------|----------------|
|         | every day | some day | every day | some day |            |
| 65      | 1.5%      | 1.5%      | 1.5%      | 1.5%      | 1.6%      |
| 67      | 1.5%      | 1.5%      | 1.4%      | 1.5%      | 2.1%      |
| 69      | 1.6%      | 1.7%      | 1.4%      | 1.7%      | 2.0%      |
| 71      | 1.6%      | 1.9%      | 1.3%      | 1.7%      | 2.1%      |
| 73      | 1.7%      | 2.0%      | 1.3%      | 1.8%      | 2.2%      |
| 75      | 1.8%      | 2.2%      | 1.3%      | 1.8%      | 2.3%      |
| 77      | 1.8%      | 2.3%      | 1.2%      | 1.7%      | 2.5%      |
| 79      | 1.9%      | 2.4%      | 1.2%      | 1.6%      | 2.6%      |
| 81      | 2.0%      | 2.5%      | 1.2%      | 1.6%      | 2.8%      |
| 83      | 2.1%      | 2.6%      | 1.3%      | 1.7%      | 2.9%      |
| 85      | 2.2%      | 2.7%      | 1.4%      | 1.8%      | 3.1%      |
| 87      | 2.3%      | 3.0%      | 1.5%      | 2.1%      | 3.3%      |
| 89      | 2.4%      | 3.3%      | 1.7%      | 2.5%      | 3.6%      |
| 91      | 2.5%      | 3.8%      | 1.9%      | 3.1%      | 3.9%      |
| 93      | 2.6%      | 4.6%      | 2.1%      | 3.9%      | 4.3%      |
| 95      | 2.8%      | 5.8%      | 2.3%      | 5.2%      | 4.6%      |
Table S3: Probabilities of Quitting, Successful Quitting, and Relapse at Ages 65-95 Years, by Sex

| Age (x) | Quitting | Successful quitting | Relapse |
|---------|----------|---------------------|---------|
|         | Every day | Some days | Every day | Some days |         |
| 65      | 59.4%     | 68.4%     | 26.4%     | 32.1%     | 57.9%   |
| 67      | 56.6%     | 66.6%     | 23.9%     | 30.1%     | 50.0%   |
| 69      | 53.4%     | 64.7%     | 20.5%     | 26.8%     | 45.8%   |
| 71      | 50.1%     | 62.7%     | 16.8%     | 22.9%     | 44.4%   |
| 73      | 46.7%     | 60.7%     | 12.9%     | 18.5%     | 44.8%   |
| 75      | 43.5%     | 58.7%     | 9.4%      | 14.0%     | 46.4%   |
| 77      | 40.5%     | 56.4%     | 6.5%      | 10.0%     | 49.3%   |
| 79      | 37.6%     | 53.9%     | 4.5%      | 6.9%      | 52.7%   |
| 81      | 35.0%     | 51.3%     | 3.5%      | 5.1%      | 56.8%   |
| 83      | 32.9%     | 48.3%     | 3.4%      | 4.7%      | 60.3%   |
| 85      | 31.5%     | 44.5%     | 3.8%      | 5.1%      | 62.3%   |
| 87      | 30.3%     | 40.9%     | 4.2%      | 5.6%      | 63.0%   |
| 89      | 29.7%     | 37.0%     | 4.3%      | 5.2%      | 61.2%   |
| 91      | 30.1%     | 32.7%     | 4.9%      | 5.1%      | 56.3%   |
| 93      | 31.0%     | 28.2%     | 5.8%      | 5.1%      | 48.8%   |
| 95      | 32.5%     | 24.3%     | 7.0%      | 5.1%      | 38.7%   |
|         |           |          |           |           |         |
| 65      | 63.1%     | 69.1%     | 36.0%     | 40.9%     | 47.7%   |
| 67      | 59.0%     | 67.3%     | 32.0%     | 38.4%     | 42.0%   |
| 69      | 55.2%     | 64.8%     | 27.9%     | 34.9%     | 39.1%   |
| 71      | 51.5%     | 61.7%     | 24.0%     | 30.7%     | 39.0%   |
| 73      | 47.7%     | 58.1%     | 20.2%     | 26.2%     | 40.3%   |
| 75      | 43.7%     | 54.2%     | 16.7%     | 21.8%     | 43.0%   |
| 77      | 39.4%     | 50.3%     | 13.4%     | 17.9%     | 46.5%   |
| 79      | 34.7%     | 46.5%     | 10.7%     | 14.7%     | 50.3%   |
| 81      | 29.7%     | 43.0%     | 8.6%      | 12.3%     | 54.0%   |
| 83      | 24.0%     | 40.3%     | 6.9%      | 11.2%     | 56.4%   |
| 85      | 18.2%     | 38.6%     | 5.6%      | 11.1%     | 56.6%   |
| 87      | 12.6%     | 38.1%     | 4.3%      | 12.1%     | 53.6%   |
| 89      | 7.8%      | 38.9%     | 2.9%      | 14.3%     | 47.7%   |
| 91      | 4.3%      | 41.3%     | 1.8%      | 17.2%     | 38.8%   |
| 93      | 2.0%      | 45.8%     | 0.9%      | 20.6%     | 28.8%   |
| 95      | 0.8%      | 52.6%     | 0.3%      | 23.8%     | 20.0%   |
Table S4: Standard Error of Estimates in Figure 2

| Age (x) | Smoking | Not smoking at all | Quitting vs. not quitting | Non-smokers vs. smokers |
|---------|---------|--------------------|--------------------------|-------------------------|
|         | Every day | Some days | All smokers | Recent | Long time | All non-smokers |       |       |
| 65      | 0.29     | 0.29      | 0.29       | 0.30   | 0.27      | 0.52           | 0.42  | 0.59  |
| 67      | 0.27     | 0.27      | 0.27       | 0.28   | 0.26      | 0.51           | 0.39  | 0.57  |
| 69      | 0.26     | 0.26      | 0.26       | 0.27   | 0.25      | 0.49           | 0.37  | 0.56  |
| 71      | 0.24     | 0.24      | 0.24       | 0.25   | 0.24      | 0.48           | 0.35  | 0.54  |
| 73      | 0.22     | 0.22      | 0.22       | 0.23   | 0.22      | 0.47           | 0.32  | 0.52  |
| 75      | 0.21     | 0.21      | 0.21       | 0.22   | 0.21      | 0.46           | 0.30  | 0.50  |
| 77      | 0.19     | 0.19      | 0.19       | 0.20   | 0.20      | 0.44           | 0.28  | 0.48  |
| 79      | 0.18     | 0.18      | 0.18       | 0.19   | 0.18      | 0.43           | 0.26  | 0.46  |
| 81      | 0.17     | 0.17      | 0.17       | 0.17   | 0.17      | 0.41           | 0.24  | 0.44  |
| 83      | 0.15     | 0.15      | 0.15       | 0.16   | 0.15      | 0.39           | 0.22  | 0.42  |
| 85      | 0.14     | 0.14      | 0.14       | 0.14   | 0.14      | 0.37           | 0.20  | 0.40  |
| 87      | 0.13     | 0.13      | 0.13       | 0.13   | 0.13      | 0.36           | 0.19  | 0.38  |
| 89      | 0.12     | 0.13      | 0.12       | 0.12   | 0.11      | 0.34           | 0.17  | 0.36  |
| 91      | 0.12     | 0.12      | 0.12       | 0.11   | 0.10      | 0.32           | 0.16  | 0.34  |
| 93      | 0.11     | 0.11      | 0.11       | 0.10   | 0.09      | 0.30           | 0.15  | 0.32  |
| 95      | 0.10     | 0.11      | 0.11       | 0.10   | 0.08      | 0.29           | 0.14  | 0.30  |

1: quit less than 2 years
2: never smoke or quit ≥ 2 years
3: difference between recent non-smokers and smokers
4: difference between all non-smokers and all smokers
Table S5: Life Expectancy by Initial Smoking Status at Ages 65-95 Years, by Sex

| Age (x) | Smoking now | Not smoking at all | Quitting vs. not quitting | Non-smokers vs. smokers |
|---------|-------------|--------------------|--------------------------|-------------------------|
|         | Every day   | Some day           | All smokers              | Recent¹                    | Long time²                  | All non-smokers | (³) | (⁴) |
| 65      | 14.8        | 15.2               | 14.9                     | 15.1                     | 18.7                      | 18.6               | 0.2* | 3.7* |
| 67      | 13.4        | 14.0               | 13.6                     | 14.5                     | 17.2                      | 17.1               | 0.9* | 3.5* |
| 69      | 12.0        | 12.8               | 12.2                     | 13.4                     | 15.7                      | 15.6               | 1.2* | 3.3* |
| 71      | 10.8        | 11.6               | 11.0                     | 12.2                     | 14.2                      | 14.1               | 1.2* | 3.1* |
| 73      | 9.6         | 10.6               | 9.9                      | 10.9                     | 12.8                      | 12.7               | 1.0* | 2.8* |
| 75      | 8.7         | 9.6                | 9.0                      | 9.6                      | 11.4                      | 11.4               | 0.7* | 2.4* |
| 77      | 7.8         | 8.7                | 8.1                      | 8.4                      | 10.2                      | 10.1               | 0.3* | 2.1* |
| 79      | 7.0         | 7.9                | 7.3                      | 7.2                      | 9.0                       | 9.0                | -0.1 | 1.6* |
| 81      | 6.4         | 7.1                | 6.6                      | 6.2                      | 7.9                       | 7.9                | -0.4 | 1.2* |
| 83      | 5.8         | 6.4                | 6.0                      | 5.5                      | 6.9                       | 6.9                | -0.5 | 0.8* |
| 85      | 5.3         | 5.7                | 5.4                      | 4.9                      | 6.0                       | 5.9                | -0.5 | 0.5* |
| 87      | 4.7         | 5.0                | 4.8                      | 4.6                      | 5.1                       | 5.1                | -0.2 | 0.3  |
| 89      | 4.2         | 4.2                | 4.2                      | 4.2                      | 4.4                       | 4.4                | 0.0  | 0.2  |
| 91      | 3.8         | 3.4                | 3.6                      | 3.6                      | 3.8                       | 3.8                | -0.1 | 0.2  |
| 93      | 3.4         | 2.8                | 3.1                      | 3.0                      | 3.3                       | 3.3                | -0.1 | 0.2  |
| 95      | 3.0         | 2.2                | 2.7                      | 2.6                      | 2.9                       | 2.9                | -0.1 | 0.2  |

|        | (³) | (⁴) |
|---------|-----|-----|
| Women   |     |     |
| 65      | 17.2| 17.4| 17.2| 18.7| 21.0| 21.0| 1.5*| 3.7*|
| 67      | 15.6| 15.9| 15.7| 17.3| 19.4| 19.3| 1.7*| 3.7*|
| 69      | 14.0| 14.4| 14.2| 15.8| 17.8| 17.7| 1.7*| 3.5*|
| 71      | 12.6| 13.0| 12.7| 14.3| 16.2| 16.1| 1.6*| 3.4*|
| 73      | 11.3| 11.6| 11.4| 12.8| 14.7| 14.6| 1.4*| 3.2*|
| 75      | 10.1| 10.4| 10.2| 11.4| 13.2| 13.2| 1.2*| 3.0*|
| 77      | 9.0  | 9.2  | 9.1  | 10.0 | 11.8| 11.8| 1.0*| 2.7*|
| 79      | 8.0  | 8.1  | 8.1  | 8.8  | 10.5| 10.4| 0.7*| 2.4*|
| 81      | 7.2  | 7.2  | 7.2  | 7.7  | 9.2 | 9.2 | 0.5*| 2.0*|
| 83      | 6.4  | 6.4  | 6.4  | 6.8  | 8.1 | 8.1 | 0.3*| 1.7*|
| 85      | 5.8  | 5.7  | 5.7  | 6.0  | 7.0 | 7.0 | 0.2*| 1.3*|
| 87      | 5.2  | 5.1  | 5.2  | 5.3  | 6.1 | 6.1 | 0.2*| 0.9*|
| 89      | 4.7  | 4.6  | 4.7  | 4.8  | 5.2 | 5.2 | 0.1 | 0.5*|
| 91      | 4.3  | 4.2  | 4.3  | 4.3  | 4.5 | 4.5 | 0.0 | 0.2*|
| 93      | 3.9  | 3.9  | 3.9  | 3.9  | 3.9 | 3.9 | 0.0 | -0.1|
| 95      | 3.6  | 3.6  | 3.6  | 3.4  | 3.3 | 3.3 | -0.2| -0.3|

¹: quit less than 2 years. ²: never smoke or quit ≥ 2 years. ³: difference between recent non-smokers and smokers. ⁴: difference between all non-smokers and all smokers. *: p < 0.05 for testing for difference between 2 groups.
### STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of cohort studies

| Section/Topic       | Item # | Recommendation                                                                 | Reported on page # |
|---------------------|--------|--------------------------------------------------------------------------------|-------------------|
| Title and abstract  | 1      | *(a)* Indicate the study’s design with a commonly used term in the title or the abstract | 2                 |
|                     |        | *(b)* Provide in the abstract an informative and balanced summary of what was done and what was found | 2                 |
| Introduction        | 2      | Explain the scientific background and rationale for the investigation being reported | 4-5               |
| Objectives          | 3      | State specific objectives, including any prespecified hypotheses                  | 5                 |
| Methods             | 4      | Present key elements of study design early in the paper                            | 5-6               |
| Study design        | 5      | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection | 6                 |
| Setting             | 6      | *(a)* Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up | 6                 |
|                     |        | *(b)* For matched studies, give matching criteria and number of exposed and unexposed  | n/a               |
| Participants        | 7      | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable | 6-7               |
| Data sources/       | 8*     | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group | 6-7               |
| measurement         |        |                                                                                   |                   |
| Bias                | 9      | Describe any efforts to address potential sources of bias                           | 9-10              |
| Study size          | 10     | Explain how the study size was arrived at                                         | n/a               |
| Quantitative variables | 11   | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why | 6-7               |
| Statistical methods | 12     | *(a)* Describe all statistical methods, including those used to control for confounding | 7-10, 20-23       |
|                     |        | *(b)* Describe any methods used to examine subgroups and interactions               | n/a               |
|                     |        | *(c)* Explain how missing data were addressed                                      | 6,25              |
|                     |        | *(d)* If applicable, explain how loss to follow-up was addressed                    | 6,25              |
|                     |        | *(e)* Describe any sensitivity analyses                                            | 9-10              |

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| Checklist Item | Required Information |
|---------------|----------------------|
| Participants  | 13*                  |
|               | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed |
|               | (b) Give reasons for non-participation at each stage |
|               | (c) Consider use of a flow diagram |
| Descriptive data | 14*              |
|               | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders |
|               | (b) Indicate number of participants with missing data for each variable of interest |
|               | (c) Summarise follow-up time (eg, average and total amount) |
| Outcome data  | 15*                  |
|               | Report numbers of outcome events or summary measures over time |
| Main results  | 16                   |
|               | (a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included |
|               | (b) Report category boundaries when continuous variables were categorized |
|               | (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period |
| Other analyses| 17                   |
|               | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses |
| Discussion    | 18                   |
| Key results   | Summarise key results with reference to study objectives |
| Limitations   | 20                   |
| Interpretation| Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence |
| Generalisability | 21                  |
|               | Discuss the generalisability (external validity) of the study results |
| Other information | 22              |
| Funding       | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based |

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.
Use of a Microsimulation Method for Assessing Dynamics of Smoking Status and Gains in Life Expectancy after Quitting among U.S. Older Adults

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| Secondary Subject Heading: | Smoking and tobacco |
| Keywords: | STATISTICS & RESEARCH METHODS, GERIATRIC MEDICINE, PUBLIC HEALTH |
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Use of a Microsimulation Method for Assessing Dynamics of Smoking Status and Gains in Life Expectancy after Quitting among U.S. Older Adults

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3 Tables, 2 Figures  Supplementary tables: 5

Appendix: Estimation of Transition Probabilities

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Abstract:

Objectives: Previous studies were unable to estimate the dynamics of smoking status in the U.S. elderly general population, and no study has assessed the benefit of quitting in terms of resultant gains in life expectancy. We proposed a novel method to estimate the percent of quitting in remaining lifetime, successful quitting, and relapse, as well as life expectancy by participants’ baseline smoking status from a large, cohort sample.

Methods: Data were from the Medicare Health Outcome Survey Cohort 15 (baseline 2012, follow-up 2014). We included respondents aged \( \geq 65 \) years \((n=164,597)\). The microsimulation method was used to project individuals’ future smoking status until death through a sequence of independent trials based on multi-state models. Sensitivity analyses were conducted to assess the impact of the model assumptions on estimates.

Results: Among 65-year old daily smokers, 61% would attempt to quit during their remaining lifetime, and 31% would quit successfully. Among 65-year old some days smokers, 69% would attempt to quit during their remaining lifetime, and 37% would quit successfully. Among 65-year old recent ex-smokers, 53% would relapse. Life expectancy at age 65 years was 20.0 (SE=0.27), 17.2 (SE=0.30), 16.2 (SE=0.29) and 15.9 (SE=0.29) years for long time non-smokers, recent ex-smokers, some days smokers, and daily smokers, respectively. Although recent ex-smokers had a higher 2-year mortality than current smokers, those who quit up to 77 years (77 for men and 87 years for women) had a significantly longer \((p<0.05)\) life expectancy. Sensitivity analysis demonstrated that the model assumptions had a relatively small impact on estimates with a maximum relative bias less than 7%.

Conclusions: This study provides detailed information regarding the dynamics of smoking status in an understudied and growing population and demonstrates the benefit of smoking cessation on life expectancy. Future research should focus on understanding specific predictors of smoking cessation.

Keywords: smoking cessation, relapse, microsimulation, multistate model
Strengths and limitations of this study

- This study fills critical gaps in the smoking cessation research by estimating gains in life expectancy after quitting among U.S. older adults.

- The large sample size of this study enables us to obtain estimates, with good reliability, at each of the 2-year age intervals from age 65 years to 95 years.

- Our method assumes all relapses occurred within 2 years of abstinence and older longtime non-smokers do not initiate smoking or experience relapse.

- We conducted extensive sensitivity analyses that demonstrate that the impact of our model assumption on all estimates was small, with the maximum relative bias less than 7%.

- This analysis did not examine factors (other than age and gender) that affected quitting and relapse or the reasons for quitting and relapse.
Introduction

In the United States, smoking is the leading cause of preventable death.[1] Yet, despite substantial evidence that older persons benefit from quitting smoking in terms of both morbidity and mortality, research on smoking cessation tends to focus on younger adults.[2,3] Older adults differ from younger adults with regard to smoking prevalence, quit attempts, and relapse.[3,4] Findings from nationwide surveys of the U.S. general population indicate that the smoking prevalence is lower among older adults than among younger adults.[3,5-7] As an example, based on the 2016 National Health Interview Survey (NHIS), 8.8% of persons aged 65 years and older were current smokers compared to 17.1% of persons aged 18 to 64 years.[7] However, compared to younger smokers, older smokers are less likely to attempt quitting in the preceding 12 months.[6] Regarding the impact of smoking on life expectancy, using data from the 2009 Behavioral Risk Factor Surveillance System (BRFSS) and the NHIS, life expectancy at age 18 was estimated to be 62.5 years for non-smokers (never or former smokers) and 53.6 years for current smokers, resulting in an average loss of 9.0 years to smoking for 18-year old smokers.[8]

Previous investigations used data from nationwide, population-based, cross-sectional surveys that relied on retrospective assessments to ascertain dynamics of smoking, such as attempts to quit, successful quitting, and smoking relapse.[5-7,9-10] These assessments were based on the following four questions from the NHIS, the National Health and Nutrition Examination Survey (NHANES), and the BRFSS: (1) “Have you smoked at least 100 cigarettes in your entire life?” (2) “Do you now smoke cigarettes every day, some days, or not at all?” (3) “During the past 12 months, have you stopped smoking for longer than a day because you were trying to quit smoking?” and (4) “How long has it been since you quit smoking cigarettes?” For example, respondents who answered “Yes” to question (3) were classified as having a recent quit attempt.[6,7] Respondents who answered “Every day” or “Some days” to question (2) and “Yes” to question (3) were classified as having a smoking relapse.[5] Successful quitting was measured by calculating the quit ratio which is the ratio of former smokers, those who answer “Yes” to question (1) and “not at all” to question (2), to ever smokers, those who answer “Yes” to question (1).[6,7,9] However, this approach cannot provide estimates of the percent of quitting.
and successful quitting for current smokers and percent of relapse for ex-smokers because the appropriate
denominators for the calculation of percentages cannot be determined. In addition, estimates based on these
questions are subject to recall bias as well as selective survival bias.

It is also difficult to quantify the impact of smoking on mortality and the benefits of quitting in terms of
years of life lost due to smoking and gains in life years after quitting.[11] To our knowledge, no study has
estimated gains in life expectancy after quitting in the older U.S. general population. A number of different
reasons exist as to why this is not a straightforward analysis. For example, health risks, in the form of chronic
diseases and premature death, may become clinically manifest only after many years of smoking. Similarly, the
impact of quitting, in the form of a decrease in mortality, may not be apparent until many years after having
quit. Conversely, being in poor health or having chronic conditions usually is the reason to quit smoking,[12,13]
and, therefore, recent ex-smokers might have a higher mortality several years after quitting as compared to
current smokers.[11] Additionally, smoking status is not a permanent state and may change throughout the
lifespan. A person may attempt to quit and relapse many times.[14,15] Because of these potential scenarios,
estimating life expectancy for individuals based on their baseline smoking status should account for transitions
between different smoking statuses during their remaining lifetime.[16] However, previous analyses of losses in
life expectancy due to smoking assumed that smoking status would be unchanged throughout the remainder of
expected lifetime for both smokers and non-smokers, and, therefore, this assumption would likely overestimate
years of life losses to smoking.[8,17,18]

Ideally, these estimates should be from a large prospective cohort that is representative of the general
population and records participants’ smoking status on a regular basis over many decades until death. Due to the
high data requirements, we developed a novel method that used a single current smoking status question,
Question (2) above, from a large, cohort sample of U.S. elderly population with a relatively short follow-up
interval. The present study describes and applies this method to estimate dynamics of smoking status of U.S.
older adults aged 65 years or older using a large, national representative legacy dataset. There are two specific aims: (1) to estimate the percentages of quitting during the remaining lifetime and successful quitting among current smokers and the percentages of relapse among recent ex-smokers (defined as less than 2 years of abstinence); and (2) to estimate life expectancy at age 65 to 95 years by respondents’ baseline smoking status. We examined whether life expectancy increased after quitting. Finally, to assess the validity of our estimates, we conducted a sensitivity analysis by examining the impact of the model assumptions on our estimates.

Methods

In this study, the term “quitting” refers to a participant who reported smoking previously and does not currently smoke. “Successful quitting” refers to an ex-smoker who has been abstinent from smoking for at least two years and remains a nonsmoker until death. “Relapse” refers to a person who reported not smoking previously and is smoking now.

Data and measures: The data were obtained from the Medicare Health Outcome Survey (HOS), a nationwide survey of Medicare beneficiaries.[19] Each year, the HOS randomly selects a cohort of Medicare beneficiaries who voluntarily enrolled in Medicare Advantage private health plans. The selected individuals who completed a baseline survey are resurveyed two years later. We used the Medicare HOS Cohort 15 whose baseline data were collected in 2012 and follow-up data were collected in 2014. This dataset contains date of death if death occurred by January 31, 2015. We included respondents who were aged 65 years or older and alive at the baseline and participated in the baseline survey. The total sample was 164,597 (Supplementary File, Table S1). Among them, 100,290 (61%) were alive at follow-up and completed the follow-up survey, and 64,597 (39%) did not participate in the follow-up survey, including 26,111 (16%) who died and 38,196 (23%) who were alive, but did not complete the survey. An additional 88 participants died after completing the follow-up survey. The average time from the baseline to follow-up survey was 730.3 days (Interquartile range, IRQ=700-730 days). The average follow-up time (from baseline to death or to January 31, 2015) was 901.1 days (IRQ= 932-1,099 days).
The Medicare HOS includes only one question on current smoking status. The survey did not ask respondents about their life time smoking status nor recent quit attempt. At both baseline and follow-up surveys, the HOS asks respondents “Do you now smoke every day, some days, or not at all?”[20] We used this question to classify respondents as daily smokers, occasional smokers, and non-smokers. Of the 164,597 individuals who participated the baseline survey, 158,964 (96.6%) answered the smoking question; of the 100,290 individuals who participated in the follow-up survey, 93,905 (93.6%) answered the smoking question (Table S1).

**Statistical Analysis:** We proposed a smoking transition model that classified non-smokers into recent ex-smokers and longtime non-smokers based on their answers to the current smoking question at the baseline and two years later. The microsimulation method was used to project individuals’ future smoking status until death through a sequence of independent trials in a first order Markov process based on multi-state models and to estimate their expected number of remaining life years (i.e., life expectancy).[21,22]

Multi-state models were used to estimate probabilities of transferring between different smoking states.[16,22] Because the baseline and follow-up surveys were 2 years apart, we constructed a multi-state model in 2-year age intervals, at ages 65, 67, … years. To illustrate the method, we describe a Markov process with k transient states (s_1,s_2,…,s_k) for k levels of smoking status and one absorbing state (s_{k+1}) for dead. Let \( p^{ij}_t = \Pr (s_{t+2} = j | s_t = i) \) be the transition probability from state s_i at age t to state s_j at age t + 2. These transition probabilities satisfy linear dependence: \( \sum_{j=1}^{k+1} p^{ij}_t = 1 \) for all i. Because s_{k+1} is the absorbing state, \( p^{k+1i}_t = 0 \) for \( i \leq k \) and \( p^{k+1,k+1}_t = 1 \).

Using the current smoking status question, we applied a multi-state model with 3 transient states, s_1,s_2, s_3 for “smoking daily”, “smoking occasionally”, and “non-smoking”, and one absorbing state (s_4) for dead (Figure 1, Model A). This model has a transition matrix
\[ P_x = [p_x^j] = \begin{bmatrix}
p_{1,1} & p_{1,2} & p_{1,3} & p_{1,4} 
p_{2,1} & p_{2,2} & p_{2,3} & p_{2,4} 
p_{3,1} & p_{3,2} & p_{3,3} & p_{3,4} 
0 & 0 & 0 & 1
\end{bmatrix}. \]

For example, \( p_{1,3} \) and \( p_{2,3} \) are probabilities of quitting for daily smokers, and some days smokers, respectively; \( p_{3,1} \) and \( p_{3,2} \) are probabilities of relapse for daily smokers and some days smokers, respectively; and \( p_{1,4}, p_{2,4}, \) and \( p_{3,4} \) are probabilities of dying for daily smokers, some days smokers, and non-smokers.

In Model A, the “non-smoking” state includes recent ex-smokers, longtime ex-smokers, and never smokers. This model assumes the same relapse and mortality rates for them. Although recent ex-smokers compose a very small proportion of the “non-smoking” group, nearly all relapses are from those with less than 2 years of abstinence.[17,23,24] Also, recent ex-smokers might have a higher mortality rate than longtime ex-smokers and never smokers. Therefore, Model A may be invalid. The main problem is that the Medicare HOS did not ask respondents about their lifetime smoking status. Therefore, we were unable to separate non-smokers into never smokers and former smokers.

To solve this problem, we partitioned the “non-smoking” state, \( s_3 \), into two mutually exclusive states: \( s_{3A} \) for “recent non-smoking” and \( s_{3B} \) for “longtime non-smoking” (Figure 1, Model B). Because never smokers and longtime ex-smokers would be unlikely to start smoking at an advanced age of 65 years or older and nearly all relapses (about 99%) were within 2 years of abstinence,[23-26] we assumed all relapses occurred within 2 years of abstinence and older longtime non-smokers do not initiate smoking or experience relapse, i.e., \( p_{t_{3B},1} = p_{t_{3B},2} = 0 \). Based on this assumption, Model B has a transition probability matrix

\[ P_x = [p_x^j] = \begin{bmatrix}
p_{1,1} & p_{1,2} & p_{1,3A} & 0 & p_{1,4} 
p_{2,1} & p_{2,2} & p_{2,3A} & 0 & p_{2,4} 
p_{3A,1} & p_{3A,2} & 0 & p_{3A,3B} & p_{3A,4} 
0 & 0 & 0 & p_{3B,3B} & p_{3B,4} 
0 & 0 & 0 & 0 & 1
\end{bmatrix}. \]
For Model B, the recent non-smoking measure was operationalized as smoking at baseline and not smoking at follow-up. The longtime non-smoking measure was operationalized as not smoking at both baseline and follow-up.

All transition probabilities \( p_{ij}, i = 1,2,3, \text{ and } j = 1,2,3,4 \) in Model A at a given age between states \( s_1, s_2, s_3 \) and \( s_4 \) can be estimated from the HOS data (details are in Appendix A1).[16] For Model B, six transition probabilities \( p^{1,1}, p^{1,2}, p^{1,4}, p^{2,1}, p^{2,2}, \text{ and } p^{2,4} \) are available from Model A directly. The remaining eight transition probabilities, \( p^{1,3A}, p^{2,3A}, p^{3A,1}, p^{3A,2}, p^{3A,3B}, p^{3B,3B}, p^{3A,4}, \text{ and } p^{3B,4} \), can be estimated based on assumptions of Model B (details are in Appendix A2).

Microsimulations: We projected the future smoking status of each individual in a synthetic cohort of persons using the microsimulation method.[21,22] For an age cohort of 1,000,000 individuals of a given initial state \( s_i \) \((i = 1, 2, 3A, 3B)\) at starting age \( x \), using the estimated transition probabilities of Model B, we simulated each individual’s smoking state at age \( x + 2, x + 4, \ldots \) iteratively until all individuals died. Percent of quitting in the remaining lifetime was estimated as the proportion ever entering the recent non-smoking state \((s_{3A})\) for a cohort of current smokers \((s_1 \text{ or } s_2)\) at the starting age \( x \). Percent of successful quitting was estimated as the proportion entering the longtime non-smoking state \((s_{3B})\) for a cohort of current smokers. Percent of relapse was estimated as the proportion entering the current smoking states \((s_1 \text{ or } s_2)\) for a cohort of recent ex-smokers \((s_{3A})\).

Life expectancy is estimated as the average number of years from the starting age to age of death for a cohort of individuals in a given initial state \( s_i (i = 1, 2, 3A, 3B) \) at starting age \( x \). If death occurred during the age interval from \( x + 2k \) to \( x + 2(k + 1) \), average years to death is \( e_x = 2k + 2a \), where \( a \) is the proportion of time lived in the 2-year age interval for persons who died during the interval. Assuming a constant mortality rate during an age interval, it can be shown that \( a = 1 - \frac{1}{\ln(1 - p)} - \frac{1}{p} \), where \( P = P^{i,4}(i = 1, 2, 3A, 3B) \) is probability of death during the age interval. When \( P \) is small and close to 0, \( a \approx 0.5 \), otherwise, \( a < 0.5 \).
The standard errors of all estimates were derived from microsimulation and includes the random variation of individuals’ outcomes conditional to transition probabilities and imprecision of the estimated transition probabilities (i.e., first and second order Monte Carlo uncertainty).[22,27]

**Sensitivity Analysis:** Our estimates relied on the assumption that all relapses occurred within 2 years of abstinence and no relapse for longtime non-smokers. This assumption may lead to underestimation of successful quitting. To assess the impact of this assumption, we conducted a sensitivity analysis by examining a model that allows relapse for non-smokers who had not smoked in the past 2+ years (Figure 1, Model C). Because relapse rates decreased with years of abstinence,[5,25,26,28] we assumed that all relapses for those who had not smoked in the past 2+ years occurred between years 2 and 4 of abstinence and there was no relapse after 4+ years of abstinence. Extending from Model B, and let states $s_{3A}, s_{3B1},$ and $s_{3B2}$ be non-smoking for $< 2$ years, 2-4 years, and $\geq 4$ years, respectively, the Model C has a transition matrix

$$P_x = [p_{ij}] = \begin{bmatrix} p_{1,1} & p_{1,2} & p_{1,3A} & 0 & 0 & p_{1,4} \\ p_{2,1} & p_{2,2} & p_{2,3A} & 0 & 0 & p_{2,4} \\ p_{3A,1} & p_{3A,2} & 0 & p_{3A,3B1} & 0 & p_{3A,4} \\ p_{3B1,1} & p_{3B1,2} & 0 & 0 & p_{3B1,3B2} & p_{3B1,4} \\ 0 & 0 & 0 & 0 & p_{3B2,3B2} & p_{3B2,4} \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}. $$

To estimate transition probabilities of Model C, we made following two assumptions:

(1) We assumed the probabilities of transferring from state $s_{3B1}$ to states $s_1$ and $s_2$ are in the form of $p^{3B1,1} = RR \times p^{3A,1}$ and $p^{3B1,2} = RR \times p^{3A,2},$ respectively, where RR is the risk ratio of relapse for state $s_{3B1}$ relative to state $s_{3A}$. Data from previous studies showed that the relapse rate for those with 2+ years of abstinence was between 5% and 13% of that for those with $\leq 2$ years of abstinence.[23-26,28] We used RR=0.05 (scenario A) and 0.15 (scenario B) as lower bound and upper bound, respectively.

(2) We expected that the mortality rates for those who had quit for between 2-4 years should be between the mortality rates for those who had quit for $>4$ years and those who quit $\leq 2$ years of the same age,[11] i.e.,
\[ p^{3A,4} \geq p^{3B1,4} \geq p^{3B2,4} \]. We used \( p^{3B1,4} = p^{3B1,4} \) (scenario 1) and \( p^{3B1,4} = p^{3A,4} \) (scenario 2) as lower bound and upper bound, respectively.

We estimated models with model parameters under four different scenarios with the combination of these scenarios: A-1, A-2, B-1, and B-2.

Nine transition probabilities \( (p_{1,1}, p_{1,2}, p_{1,3A}, p_{1,4}, p_{2,1}, p_{2,2}, p_{2,3A}, p_{2,4}, p^{3A,4}) \) are from Model B directly. The remaining nine transition probabilities \( (p_{3A,1}, p_{3A,2}, p_{3A,3B1}, p_{3A,3B2}, p_{3B1,1}, p_{3B1,2}, p_{3B1,3B2}, p_{3B1,4}, p^{3B2,3B2}, p_{3B2,4}) \) can be estimated based on Model C assumptions. Details of transition probability estimation for Model C are available in Appendix A3. We compared estimates from Model B to that from Model C.

**Patient and public involvement:** Patients and/or the public were not involved in the design, conduct, reporting, or dissemination plans of this research.

**Results**

At baseline, the average participant age was 75.1 years, with 53% of participants between 65 and 74 years old, 34% of participants between 75 and 84 years old, and 13% of participants 85 years or older (Supplementary File, Table S1). Women comprised 58% of the sample, and white, non-Hispanics 76% of the sample. About 10% participants reported currently smoking, including 6.6% daily smokers and 3.1% occasional smokers. At the follow-up survey, about 8% participants reported currently smoking, including 5.2% daily smokers and 2.7% some days smokers. Men were more likely (about 25% more) to be current smokers than women.

Table 1 presents the estimated transition probabilities for each the four smoking statuses: daily smoking, some days smoking, recent non-smoking, and longtime non-smoking. These results provide 2-year quit rates for
current smokers and 2-year relapse rates for recent quitters. As an example, for 65-year old daily smokers, 83.1% (73.0% daily and 10.1% some days) would still smoke at age 67 and 12.2% would quit; as a comparison, for a cohort of 65-year old some days smokers, at age 67 years, 75.7% (16.5% daily and 59.2% some days) would still smoke and 19.4% would quit. For 65-year old recent ex-smokers, at age 67 years, 53.2% (18.4% daily and 34.8% some days) would smoke again (relapse), and 40.5% would still abstain from smoking. These results also provide 2-year mortality by smoking status. Recent ex-smokers had the highest 2-year mortality rates, followed by daily smokers and some days smokers, and longtime non-smokers had the lowest 2-year mortality rates. For example, the 2-year mortality rates among 65-year-old persons were 6.3%, 4.8%, 5.0%, and 2.0% for the four groups, respectively.

Table 1: Transition Probabilities between Different Smoking States at Ages 65-95 Years

| Age (x) | Transfer from daily smoking ($s_1$) to some days smoking ($s_2$) and recent non-smoking ($s_{3A}$), or to longtime non-smoking ($s_{3B}$) and dead ($s_4$) | Transfer from someday smoking ($s_2$) to recent non-smoking ($s_{3A}$), or to longtime non-smoking ($s_{3B}$) and dead ($s_4$) |
|---------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| 65      | daily smoking 73.0%, some days smoking 10.1%, recent non-smoking 12.2%, dead 4.8%                                                                               | daily smoking 16.5%, some days smoking 59.2%, recent non-smoking 19.4%, dead 0.0%                  |
| 66      | daily smoking 71.6%, some days smoking 9.8%, recent non-smoking 12.6%, dead 6.0%                                                                               | daily smoking 16.4%, some days smoking 57.2%, recent non-smoking 20.9%, dead 0.0%                  |
| 67      | daily smoking 70.2%, some days smoking 9.7%, recent non-smoking 12.8%, dead 7.4%                                                                               | daily smoking 16.3%, some days smoking 55.8%, recent non-smoking 21.8%, dead 0.0%                  |
| 68      | daily smoking 68.5%, some days smoking 9.8%, recent non-smoking 12.6%, dead 9.0%                                                                               | daily smoking 16.2%, some days smoking 54.7%, recent non-smoking 22.1%, dead 0.0%                  |
| 69      | daily smoking 66.8%, some days smoking 10.1%, recent non-smoking 12.3%, dead 10.8%                                                                               | daily smoking 16.0%, some days smoking 53.8%, recent non-smoking 22.0%, dead 0.0%                  |
| 70      | daily smoking 65.2%, some days smoking 10.3%, recent non-smoking 11.9%, dead 12.6%                                                                               | daily smoking 15.7%, some days smoking 53.1%, recent non-smoking 21.7%, dead 0.0%                  |
| 71      | daily smoking 63.4%, some days smoking 10.4%, recent non-smoking 11.5%, dead 14.7%                                                                               | daily smoking 15.4%, some days smoking 52.1%, recent non-smoking 21.3%, dead 0.0%                  |
| 72      | daily smoking 61.6%, some days smoking 10.4%, recent non-smoking 11.1%, dead 16.9%                                                                               | daily smoking 15.0%, some days smoking 50.7%, recent non-smoking 21.0%, dead 0.0%                  |
| 73      | daily smoking 60.0%, some days smoking 10.1%, recent non-smoking 10.8%, dead 19.1%                                                                               | daily smoking 14.5%, some days smoking 48.9%, recent non-smoking 20.8%, dead 0.0%                  |
| 74      | daily smoking 58.2%, some days smoking 9.5%, recent non-smoking 10.7%, dead 21.6%                                                                               | daily smoking 13.8%, some days smoking 46.4%, recent non-smoking 21.1%, dead 0.0%                  |
| 75      | daily smoking 56.3%, some days smoking 8.6%, recent non-smoking 10.8%, dead 24.3%                                                                               | daily smoking 13.1%, some days smoking 42.8%, recent non-smoking 21.9%, dead 0.0%                  |
| 76      | daily smoking 54.3%, some days smoking 7.3%, recent non-smoking 11.1%, dead 27.3%                                                                               | daily smoking 12.3%, some days smoking 38.4%, recent non-smoking 23.3%, dead 0.0%                  |
| 77      | daily smoking 52.3%, some days smoking 5.7%, recent non-smoking 11.6%, dead 30.4%                                                                               | daily smoking 11.3%, some days smoking 33.1%, recent non-smoking 25.6%, dead 0.0%                  |
| 78      | daily smoking 50.2%, some days smoking 4.0%, recent non-smoking 12.1%, dead 33.7%                                                                               | daily smoking 10.1%, some days smoking 26.9%, recent non-smoking 29.0%, dead 0.0%                  |
| 79      | daily smoking 47.9%, some days smoking 2.4%, recent non-smoking 12.4%, dead 37.2%                                                                               | daily smoking 8.7%, some days smoking 19.7%, recent non-smoking 33.6%, dead 0.0%                   |
| 80      | daily smoking 45.3%, some days smoking 1.2%, recent non-smoking 12.3%, dead 41.1%                                                                               | daily smoking 7.3%, some days smoking 11.5%, recent non-smoking 39.9%, dead 0.0%                   |

Transfer from recent non-smoking ($s_{3A}$) to daily smoking ($s_1$), some days smoking ($s_2$), or to recent non-smoking ($s_{3A}$), or to longtime non-smoking ($s_{3B}$) and dead ($s_4$).

Transfer from longtime non-smoking ($s_{3B}$) to daily smoking ($s_1$), some days smoking ($s_2$), or to recent non-smoking ($s_{3A}$), or to longtime non-smoking ($s_{3B}$) and dead ($s_4$).
| Age | $s_1$  | $s_2$  | $s_3A$ | $s_3B$ | $s_4$  | $s_1$  | $s_2$  | $s_3A$ | $s_3B$ | $s_4$  |
|-----|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 65  | 18.4%  | 34.8%  | 0%     | 40.5%  | 6.3%   | 0%     | 0%     | 0%     | 0%     | 98.0%  |
| 67  | 17.2%  | 28.9%  | 0%     | 47.0%  | 6.9%   | 0%     | 0%     | 0%     | 0%     | 97.6%  |
| 69  | 16.6%  | 26.0%  | 0%     | 49.5%  | 7.9%   | 0%     | 0%     | 0%     | 0%     | 97.1%  |
| 71  | 16.5%  | 25.2%  | 0%     | 49.1%  | 9.2%   | 0%     | 0%     | 0%     | 0%     | 96.4%  |
| 73  | 16.7%  | 25.8%  | 0%     | 46.6%  | 10.9%  | 0%     | 0%     | 0%     | 0%     | 95.5%  |
| 75  | 17.2%  | 27.5%  | 0%     | 42.4%  | 12.9%  | 0%     | 0%     | 0%     | 0%     | 94.5%  |
| 77  | 17.7%  | 30.1%  | 0%     | 36.7%  | 15.4%  | 0%     | 0%     | 0%     | 0%     | 93.1%  |
| 79  | 18.1%  | 33.4%  | 0%     | 30.2%  | 18.3%  | 0%     | 0%     | 0%     | 0%     | 91.4%  |
| 81  | 18.2%  | 36.9%  | 0%     | 23.6%  | 21.3%  | 0%     | 0%     | 0%     | 0%     | 89.4%  |
| 83  | 17.9%  | 39.9%  | 0%     | 17.7%  | 24.4%  | 0%     | 0%     | 0%     | 0%     | 86.8%  |
| 85  | 17.1%  | 41.8%  | 0%     | 13.6%  | 27.5%  | 0%     | 0%     | 0%     | 0%     | 83.5%  |
| 87  | 15.7%  | 41.7%  | 0%     | 12.5%  | 30.1%  | 0%     | 0%     | 0%     | 0%     | 79.5%  |
| 89  | 13.8%  | 39.1%  | 0%     | 15.5%  | 31.6%  | 0%     | 0%     | 0%     | 0%     | 75.0%  |
| 91  | 11.5%  | 34.0%  | 0%     | 22.6%  | 31.9%  | 0%     | 0%     | 0%     | 0%     | 69.9%  |
| 93  | 9.0%   | 27.1%  | 0%     | 28.2%  | 35.7%  | 0%     | 0%     | 0%     | 0%     | 64.3%  |
| 95  | 6.6%   | 19.5%  | 0%     | 32.4%  | 41.5%  | 0%     | 0%     | 0%     | 0%     | 58.5%  |

$s_1$: daily smoking, $s_2$: some days smoking, $s_3A$: recent non-smoking, $s_3B$: longtime non-smoking, $s_4$: dead

Figure 2 presents percentages of quitting in the remaining lifetime and successful quitting for current smokers, respectively, and percentages of relapse for recent ex-smokers. Standard errors of estimates are available in Supplementary File (Table S2). For example, among 65-year old daily smokers, 61.3% (SE=1.5%) would quit in their remaining lifetime, and 31.5% (SE=1.5%) would quit successfully. Among 65-year old recent ex-smokers, 53.2% (SE=1.6%) would relapse. The probabilities of relapse are the same regardless of how many years ago someone quit because of the model assumption, i.e., all relapses were within 2 years of quitting. Although the percentages of quitting in the remaining lifetime were similar between men and women (Supplementary File, Table S3), women were more likely to quit smoking successfully and less likely to relapse than men.

Life expectancy at a given age by participants’ baseline smoking status are in Table 2, with standard errors in Supplementary File (Table S4). For example, life expectancy at age 65 years was 20.0 (SE=0.27), 17.2 (SE=0.30), 16.2 (SE=0.29) and 15.9 (SE=0.29) years for longtime non-smokers, recent ex-smokers, some days
smokers, and daily smokers, respectively. Quitting between 65 and 77 years of age had a significantly (p<0.05) longer life expectancy as compared to current smokers. All non-smokers had a significantly longer life expectancy than did all current smokers between the ages of 65 to 87 years. When examined by gender (Supplementary File, Table S5), the difference in life expectancy between non-smokers and smokers was similar between men and women. However, quitting smoking contributed to slightly greater gains in life expectancy among women than men. Men benefit from quitting up to age 77 years, while women benefit from quitting up to age 87 years.

Table 2: Life Expectancy by Baseline Smoking Status at Ages 65-95 Years

| Age (x) | Smoking | Not smoking at all | Quitting vs. not quitting | Non-smokers vs. smokers |
|---------|---------|-------------------|--------------------------|------------------------|
|         | Daily   | Some days         | All smokers              | Recent¹                | Long time²             | All non-smokers |                           |                           |
| 65      | 15.9    | 16.2              | 16.0                     | 17.2                   | 20.0                   | 19.9               | 1.2*                    | 3.9*                    |
| 67      | 14.4    | 14.9              | 14.6                     | 16.0                   | 18.4                   | 18.3               | 1.4*                    | 3.8*                    |
| 69      | 13.0    | 13.6              | 13.2                     | 14.6                   | 16.8                   | 16.8               | 1.5*                    | 3.6*                    |
| 71      | 11.7    | 12.3              | 11.9                     | 13.2                   | 15.3                   | 15.3               | 1.4*                    | 3.4*                    |
| 73      | 10.5    | 11.1              | 10.7                     | 11.8                   | 13.8                   | 13.8               | 1.2*                    | 3.1*                    |
| 75      | 9.4     | 10.0              | 9.6                      | 10.5                   | 12.5                   | 12.4               | 0.9*                    | 2.8*                    |
| 77      | 8.4     | 8.9               | 8.6                      | 9.2                    | 11.1                   | 11.1               | 0.6*                    | 2.5*                    |
| 79      | 7.6     | 8.0               | 7.7                      | 8.1                    | 9.9                    | 9.8                | 0.4                     | 2.1*                    |
| 81      | 6.8     | 7.2               | 6.9                      | 7.1                    | 8.7                    | 8.7                | 0.1                     | 1.7*                    |
| 83      | 6.2     | 6.4               | 6.2                      | 6.2                    | 7.6                    | 7.6                | 0.0                     | 1.4*                    |
| 85      | 5.6     | 5.7               | 5.6                      | 5.5                    | 6.6                    | 6.6                | -0.1                    | 1.0*                    |
| 87      | 5.0     | 5.1               | 5.1                      | 5.0                    | 5.7                    | 5.7                | -0.1                    | 0.7                     |
| 89      | 4.6     | 4.6               | 4.6                      | 4.5                    | 5.0                    | 5.0                | -0.1                    | 0.4                     |
| 91      | 4.1     | 4.1               | 4.1                      | 4.2                    | 4.3                    | 4.3                | 0.1                     | 0.2                     |
| 93      | 3.7     | 3.7               | 3.7                      | 3.7                    | 3.7                    | 3.7                | 0.1                     | 0.0                     |
| 95      | 3.3     | 3.3               | 3.3                      | 3.3                    | 3.2                    | 3.2                | 0.0                     | -0.1                    |

¹: quit less than 2 years  
²: never smoke or quit > 2 years  
³: difference between recent non-smokers and all smokers  
⁴: difference between all non-smokers and all smokers  
*: p < 0.05 for testing for difference between 2 groups.

Sensitivity Analysis Results: Finally, we examined the impact of the model assumption (no relapse among longtime non-smokers) on our estimates by comparing estimates from Model B to estimates from Model C.
which allows relapse for non-smokers with 2+ years’ abstinence (Table 3). The model assumption had no or a very small impact on estimation of percent of quitting in the remaining lifetime, percent of relapse, and life expectancy for longtime non-smokers, as demonstrated by the similar estimates from Model B and Model C. In most scenarios, the model assumption underestimated percent of successful quitting slightly, as estimates from Model B were about 0.8% to 2.7% lower than that from Model C, with relative bias from -2.2% to -6.6%; and overestimated life expectancy slightly for current smokers and recent ex-smokers, as estimates from Model B were about 0.1-1.0 years higher than that from Model C, with relative bias from 0.4% to 5.9%.
Table 3: Sensitivity Analysis – Assess the Validity of Model Assumption

| Outcomes 1 | Model B | Model C | Bias | Relative bias |
|------------|---------|---------|------|---------------|
|            | Scenario A-1 | Scenario A-2 | Scenario B-1 | Scenario B-2 | Scenario A-1 | Scenario A-2 | Scenario B-1 | Scenario B-2 |
| Quitting   |         |         |      |               |
| Daily smokers | 61.3%  | 61.2%  | 61.2% | 61.2%         | 0%   | 0%   | 0.1%  | 0.1%          | 0.1%  | 0.1% | 0.1% | 0.1% |
| Some days smokers | 68.6%  | 68.6%  | 68.5% | 68.6%         | 0%   | 0%   | 0.0%  | 0.1%          | 0.0%  | 0.0% | 0.0% | 0.1% |
| Successful quitting |       |         |      |               |
| Daily smokers | 31.5%  | 32.2%  | 32.2% | 33.7%         | -0.8% | -0.7% | -2.2% | -2.2%         | -2.3% | -2.3% | -6.6% | -6.6% |
| Some days smokers | 36.8%  | 37.6%  | 37.6% | 39.2%         | -0.8% | -0.8% | -2.4% | -2.4%         | -2.2% | -2.2% | -6.2% | -6.2% |
| Relapse    | 53.2%  | 53.1%  | 53.1% | 52.9%         | 0.1%  | 0.1%  | 0.3%  | 0.3%          | 0.2%  | 0.2% | 0.6% | 0.6% |
| Life expectancy |       |         |      |               |
| Daily smokers | 15.9   | 15.8   | 15.7  | 15.7          | 0.1   | 0.2   | 0.2   | 0.5           | 0.4%  | 1.3% | 1.2% | 3.1% |
| Some days smokers | 16.2   | 16.2   | 16.0  | 16.0          | 0.1   | 0.2   | 0.2   | 0.6           | 0.5%  | 1.5% | 1.5% | 3.6% |
| Recent ex-smokers 2 | 17.2   | 17.1   | 16.8  | 16.8          | 0.2   | 0.4   | 0.5   | 1.0           | 0.9%  | 2.4% | 2.8% | 5.9% |
| Longtime nonsmokers 3 | 20.0   | 20.0   | 20.0  | 20.0          | 0.0   | 0.0   | 0.0   | 0.0           | 0.1%  | 0.1% | 0.1% | 0.2% |

1: all estimates are at age 65 years
2: quit less than 2 years
3: never smoke or quit ≥ 2 years

Scenario A-1: when relapse rate for those with 2+ years of abstinence was 5% of that for those with ≤ 2 years of abstinence; and mortality rate for those who had quit for between 2-4 years equals mortality rate for those who had quit for >4 years of the same age
Scenario A-2: when relapse rate for those with 2+ years of abstinence was 5% of that for those with ≤ 2 years of abstinence; and mortality rate for those who had quit for between 2-4 years equal mortality rate for those who had quit ≤ 2 years of the same age
Scenario B-1: when relapse rate for those with 2+ years of abstinence was 15% of that for those with ≤ 2 years of abstinence; and mortality rate for those who had quit for between 2-4 years equal mortality rate for those who had quit for >4 years of the same age
Scenario B-2: when relapse rate for those with 2+ years of abstinence was 15% of that for those with ≤ 2 years of abstinence; and mortality rate for those who had quit for between 2-4 years equal mortality rate for those who had quit ≤ 2 years of the same age
Discussion

Summary of findings: This study provides detailed information regarding the dynamics of smoking status as well as the benefit of smoking cessation on life expectancy among U.S. older adults. Not surprisingly, we found that smoking was associated with a significantly reduced life expectancy and that gains in life expectancy could be achieved with quitting up to age 77 years (up to 77 years for men, and up to 87 years for women). These results on the impact of smoking and smoking cessation on life expectancy among older adults are the first reported in the literature and fill critical gaps in the smoking cessation research. Yet, in terms of quitting, although approximately two thirds of 65-year-old smokers will attempt to quit smoking during their remaining lifetime, only about one third will be able to quit successfully, while about one in every two 65-year-old recent ex-smokers will relapse. Our estimates are consistent with previous analyses of the probability of relapse or successful quitting and the probability of quit attempts.[5-7,9,10]

As the age pyramid for the U.S. shifts, due to a greater proportion of persons aged 65 and older, investigators have sought to characterize the range of health trajectories among the elderly.[29] Because of the trend of an increasing percentage of persons 65 and over in the U.S. population, the total number of elderly persons who smoke may increase even if the prevalence of smokers is unchanged.[3] Understanding the age differences in cessation and relapse rates as well as benefit of quitting is critical, given that smoking patterns and predictors may differ between younger and older populations. According to 2017 NHIS data, recent successful cessation tends to decrease with age and is lowest among adults 65 and older.[3,30] The elderly population represent a heterogeneous group, often being categorized into different strata based on chronological and functional-age, and the dynamics of smoking may differ between young-old (65-74), middle-old (75-84), and old-old (85 and over).[31,32] The large sample size of the Medicare HOS data enables us to obtain estimates, with good reliability, at each of the 2-year age intervals from age 65 years to 95 years, and this is one of the strengths of our study.
Methodological considerations: Many previous investigations of smoking cessation and relapse in the U.S. general population relied on questions of previous quitting attempts and years since quitting from large, nationwide, cross-sectional surveys such as the NHIS, NHANES, and BRFSS.[5-7,9,10] The main weakness of this approach is the inability to calculate percent of successful quitting and relapse as well as potential recall bias and selective survival bias. Although some studies used cohort data to analyze the dynamics of smoking, the sample sizes of these studies were usually too small to provide reliable estimates.[25,33] Furthermore, these cohort studies used either clinical samples or non-representative samples of the general population.

We proposed a method based on the microsimulation method that constructs a synthetic cohort of participants with the same baseline smoking status by simulating each individual’s future smoking status until death. This method is novel through using a single current smoking question contained in a large, cohort survey of the U.S. general elderly population with a relatively short follow-up. In this study, the smoking status is assessed and the probabilities of changing smoking status were assessed at two time points. The respondents’ previous smoking status was obtained by modeling transition probabilities between different smoking status from baseline and follow-up surveys. We simulated respondents’ future smoking status through a sequence of independent trials based on transition probabilities between different smoking states from multi-state models.

All transition probabilities can be estimated by assuming no smoking relapse or initiation for longtime non-smokers, which includes never smokers and former smokers who quit smoking for more than 2 years. We made this assumption based on: (1) Nearly half of older adults had never smoked before and they were very unlikely to start smoking for the first time. The smoking initiation rate decreased with age after 18 years of age.4,34 Data from the 2003-2010 the NHANES indicate that among ever smokers aged 65 years or older, only 0.1% started smoking at age 65 years or later.35 (2) Relapse rates would be much lower after 2+ years of abstinence. Previous studies uniformly showed that relapse rates decreased with years of abstinence.[5,23-26,28] For example, data from 1,449 former smokers in California showed that the likelihood of relapse for those with 2+ years of abstinence was about 93% lower than that for those with less than 2 years of abstinence.[26]
Additionally, our sensitivity analysis demonstrated that, for most scenarios, the impact on our estimates was small, with the maximum relative bias less than 7%.

Previous estimates of the impact of smoking on life expectancy in general population relied on the assumption that smoking status would be unchanged throughout the remaining lifetime.[8,17,18] As a result, these studies would likely overestimate years of life losses to smoking. The present study was able to account for the possible change in smoking statuses during the remaining lifetime when estimating losses in years of life expectancy to smoking and years of life gained after quitting. By doing so, our estimates were less biased. Moreover, with the application of the microsimulation method, this study was able to estimate probability of successful quitting while previous studies were unable to make such calculations.[6,7,9]

**Limitations:** First, because this analysis is based on a survey of Medicare beneficiaries who voluntarily enrolled in private Medicare Advantage health plans, the current sample may be younger and healthier than the overall Medicare population.[36] Second, the smoking status was based on self-reported data. However, using self-reported smoking status would be unlikely to have a large impact on our conclusions. Even if some participants underreported their smoking history, it would not overestimate quitting attempts or underestimate relapse because underreports were at both baseline and follow-up. Furthermore, underreporting would not overestimate gains in life expectancy after quitting. Third, respondents reported their current smoking status, and the difference between “smoke some days” and “not smoke at all” in question “Do you now smoke?” is not very clear. Fourth, we assumed only a single transition from baseline to follow-up, and transitions were made at the end of the time interval. This assumption can lead to underestimating percentages of quitting and relapse.[16] Fifth, our analysis did not examine factors (other than age and gender) that affected quitting and relapse or the reasons for quitting and relapse. This is because many of these factors are time-varying variables. In order to include these variables in the analysis, values of these variables would need to be treated as additional transitional states which would make our model too complicated to estimate.
**Conclusions:** This study estimated smoking patterns (quitting and relapse) and the benefit of quitting in a traditionally overlooked demographic subgroup.[3,31] These estimates are currently unavailable for the U.S. general population of older adults and would enable an understanding of the trajectory and impact of tobacco use. Such information also would help guide the investment of smoking cessation services as the population ages. Future data collection should include a respondent’s number of prior quit attempts and times advised to quit smoking, given that both will influence quit rates and, ultimately, guide resource allocation and risk messaging. [15,37] Additionally, further investigations should aim to develop a broader understanding of smoking cessation predictors to identify specific strategies that might work best for the elderly based on specific sociodemographic features or chronic conditions.
Data availability statement: This study is a secondary data analysis using the Limited Data Set (LDS) of the HOS from the U.S. Centers for Medicare & Medicaid Services (CMS). The dataset contains potentially identifying or sensitive patient information (e.g., participants’ zip code, date of birth, date of death, etc.). A signed Data Use Agreement (DUA) with CMS is required to obtain LDS data files (https://www.cms.gov/Research-Statistics-Data-and-Systems/Files-for-Order/LimitedDataSets/HOS). In order to request a LDS files, investigators must follow the instructions on this link: https://www.cms.gov/Research-Statistics-Data-and-Systems/Files-for-Order/Data-Disclosures-Data-Agreements/EPPEpilot-LDSS.

Ethical approval statement: The study was reviewed and approved by the Columbia University Medical Center institutional review board (IRB-AAAR4154).

Contributors: HJ was in charge of the conceptualization, methodology, software, validation, and data curation. Both authors (HJ and EIL) were involved in the writing, editing, and visualization; both authors read and approved the final manuscript.

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Figure 1: Transition Models of Smoking Status.

Figure 2: Percent of Quitting in Remaining Lifetime, Successful Quitting, and Relapse by Age

Legend

Panel 1: Percent of Quitting
  Daily smokers
  Some days smokers

Panel 2: Percent of Successful Quitting
  Daily smokers
  Some days smokers

Panel 3: Percent of Relapse
Figure 1: Transition Models of Smoking Status.

66x71mm (600 x 600 DPI)
Figure 2: Percent of Quitting in Remaining Lifetime, Successful Quitting, and Relapse by Age

Legend
Panel 1: Percent of Quitting
Daily smokers
Some days smokers
Panel 2: Percent of Successful Quitting
Daily smokers
Some days smokers
Panel 3: Percent of Relapse

62x101mm (600 x 600 DPI)
Appendix: Estimation of Transition Probabilities

A1. Estimation for Model A: Individuals with missing smoking status at both baseline and follow-up surveys were excluded from all analyses. Individuals who did not participate the follow-up survey and individuals with missing smoking status at one of the two surveys were included in estimation of probability of death only and were excluded from the estimation of transition between different smoking statuses.

For Model A, all transition probabilities \( p_t^{ij} \) from age \( t \) to \( t+2 \) \((t=65, 67, \ldots)\) between three smoking states \((s_1, s_2, s_3)\) were obtained by estimating instantaneous transition rates at age \( t \), \( \mu_t^{ij} = \lim_{\Delta \to 0} \frac{Pr(s_t+\Delta=j|s_t=i)}{\Delta} \), from a log-linear model with age (as a cubic polynomial function) as a time-dependent predictor. Assuming a constant instantaneous transition rate in an age interval, we obtained transition probability as \( p_t^{ij} = 1 - \exp(-2\mu_t^{ij}) \).

The probability of death \( p_t^{i4} \) for smoking state \( s_i \) \((i=1,2,3)\) during age interval \( t \) to \( t+2 \) was estimated based on the probability of death for the total population and hazard ratio of death for each state relative to the reference group (“not smoking”) at different ages. Using data estimated from the 2012 U.S. life tables, let \( p_t \) be probability of death, and \( l_t^i \) be number of persons surviving to age \( t \) in state \( s_i \), and \( l_t \) be number of persons surviving to age \( t \). Using an estimation from a Cox proportional hazard model with age as a time-varying covariate from the HOS data, let \( h_t^i \) \((i=1,2)\) be the hazard ratio of death for state \( s = (s_2, s_3) \) relative to the reference state \((s_1)\) at age \( t \). Assuming a constant risk of death during each age interval, we estimated \( p_t^{i4} \) \((i=1,2,3)\) by solving the following nonlinear equations numerically:

\[
\sum_{i=1}^{3} l_t^i p_t^{i4} = l_t p_t
\]

\[
p_t^{ik+1} = 1 - (1 - p_t^{1k+1})^{h_t^i}, \quad i = 1, 2.
\]
A2. Estimation for Model B: Six transition probabilities \((p_{1,1}, p_{1,2}, p_{1,4}, p_{2,1}, p_{2,2}, \text{ and } p_{2,4})\) are from Model A directly. To estimate remaining eight transition probabilities: \(p_{1,3A}, p_{2,3A}, p_{3A1}, p_{3A2}, p_{3A3B}, p_{3B3B}, p_{3A4}, \text{ and } p_{3B4}\), let \(w\) be the proportion in state \(s_{3A}\) among total non-smoking states (i.e., in \(s_{3A}\) or \(s_{3B}\)). We estimated proportions in state \(s_{3A}\) and state \(s_{3B}\) among the total population at age \(t\) from logistic models and obtained \(w\) from these two proportions as \(w = \frac{Pr(s_{3A}=1)}{Pr(s_{3A}=1)+Pr(s_{3A}=1)}\). Let \(HR_{3A:3B}\) be the hazard ratio of death for state \(s_{3A}\) relative to state \(s_{3B}\), and \(HR_{3A:3B}\) at age \(t\) were estimated from a Cox proportional hazard model with age as a time-varying covariate from the HOS data.16

Given that \(p_{1,3}, p_{2,3}, p_{3,4}, p_{3,2}, p_{3,3}, p_{3,4}, w, \text{ and } HR_{3A:3B}\) were known, we can obtain these eight unknowns by solving following eight equations:

(1) \(p_{1,3A}(\text{Model B}) = p_{1,3} (\text{Model A});\)
(2) \(p_{2,3A}(\text{Model B}) = p_{2,3} (\text{Model A});\)
(3) \(wp_{3A1}(\text{Model B}) = p_{3,1} (\text{Model A});\)
(4) \(wp_{3A2}(\text{Model B}) = p_{3,2} (\text{Model A});\)
(5) \(p_{3B3B} + p_{3B4} = 1;\)
(6) \(wp_{3A3B} + (1 - w)p_{3B3B} (\text{Model B}) = p_{3,3}(\text{Model A});\)
(7) \(wp_{3A4} + (1 - w)p_{3B4}(\text{Model B}) = p_{3,4}(\text{Model A});\)
(8) \(p_{3A4} = 1 - (1 - p_{3B4})^{HR_{3A:3B}}.\)

Equations (1) and (2) are based on the number of (daily and occasional) smokers who become nonsmokers in Model B which equals that in Model A; (3) and (4) are based on recent nonsmokers who become smokers in Model B which is equal to the nonsmokers who become smokers in Model A; (5) is based on linear dependence, \(\Sigma_{j=1}^{k+1} p_{ij} = 1\) for \(i = 3B\); (6) is based on the number of nonsmokers (both recent and longtime) who become longtime nonsmokers in Model B being equal to the number of nonsmokers who remain nonsmokers in Model A; (7) is based on the number of deaths for nonsmokers (recent and longtime) in Model B being equal to the
number of deaths for non-smokers in Model A; and (8) is based on the relationship between the probability of
death for recent non-smokers and long-time non-smokers.

Solutions for \( p_{1,3A} \), \( p_{2,3A} \), \( p_{3A,1} \), and \( p_{3A,2} \) can be obtained directly from equations (1)-(4), while
solutions for \( p_{3A,3B} \), \( p_{3B,3B} \), \( p_{3A,4} \), and \( p_{3B,4} \) are obtained by solving nonlinear equations (5)-(8) numerically.

**A3. Estimation for Model C:** Nine transition probabilities (\( p_{1,1}, p_{1,2}, p_{1,3A}, p_{1,4}, p_{2,1}, p_{2,2}, p_{2,3A}, p_{2,4} \), and
\( p_{3A,4} \)) are from Model B directly. The remaining nine transition probabilities: \( p_{3A,1}, p_{3A,2}, p_{3A,3B1}, p_{3B1,1}, p_{3B1,2}, p_{3B1,3B2}, p_{3B1,4}, p_{3B2,3B2}, \) and \( p_{3B2,4} \), can be estimated using the similar method described in A.2. Let
\( w_1 = \frac{Pr(s_{3A}=1)}{Pr(s_{3A}=1)+Pr(s_{3B1}=1)} \) and \( w_2 = \frac{Pr(s_{3B1}=1)}{Pr(s_{3B1}=1)+Pr(s_{3B2}=1)} \). Because \( Pr(s_{3B} = 1) \) and \( Pr(s_{3A} = 1) \) are available
from Model B (see Appendix A.2) and \( Pr(s_{3B1} = 1) + Pr(s_{3B2} = 1) = Pr(s_{3B} = 1) \), we just need to estimate
\( Pr(s_{3B1} = 1) \) in order to obtain \( w_1 \) and \( w_2 \). Let \( l_x^i \) be number of persons in state \( s_i \) at age \( x \). Based on Model C
definition, the number of persons in state \( s_{3B1} \) at age \( x \) equals the number of persons in state \( s_{3A} \) at age \( x - 2 \)
minus the number of persons who died between age \( x - 2 \) and \( x \), i.e., \( l_x^{3B1} = l_x^{3A}(1 - p_{x-2} - p_{x-2} - p_{x-2}) \).
We can obtain \( Pr(s_{3B1} = 1) \) using this equation.

Given that \( w_1 \) and \( w_2 \) are known, we can obtain the remaining ten unknowns by solving the following
nine equations numerically:

1. \( p_{3B1,1} = RR \times p_{3A,1} \)
2. \( p_{3B1,2} = RR \times p_{3A,2} \)
3. \( p_{3B1,4} = p_{3B2,4} \) or \( p_{3B1,4} = p_{3B,4} \)
4. \( w_1 p_{3A,1} + (1 - w_1) p_{3B1,1} \) \( (Model \ C) = p_{3A,1} \) \( (Model \ B) \)
5. \( w_1 p_{3A,2} + (1 - w_1) p_{3B1,2} \) \( (Model \ C) = p_{3A,2} \) \( (Model \ B) \)
6. \( p_{3A,3B1} \) \( (Model \ C) = p_{3A,3B} \) \( (Model \ B) \)
7. \( w_2 p_{3B1,3B2} + (1 - w_2) p_{3B2,3B2} \) \( (Model \ C) = p_{3B,3B} \) \( (Model \ B) \)
Equations (1) and (2) are Model C assumption 1. We used $RR = 0.05$ or $0.15$ for lower and upper bound, respectively; (3) is Model C assumption 2. We used $p^{3B1,4} = p^{3B2,4}$ or $p^{3B1,4} = p^{3A,4}$ for lower and upper bound, respectively; (4) and (5) are based on the number of nonsmokers (both $3A$ and $3B1$) who become (daily and occasional) smokers in Model C being equal to the number of recent nonsmokers ($3A$) who become smokers in Model B; (6) is based on the number of recent quitters ($3A$) who become longtime nonsmokers (2-4 years abstinence, $3B1$) in Model C being equal to the number of recent quitters becoming longtime nonsmokers ($3B$) in Model B; (7) is based on the number of total longtime smokers ($3B1$ and $3B2$) who remain longtime nonsmokers ($3B2$ only) in Model C being equal to the number of longtime smokers ($3B$) who remain longtime nonsmokers ($3B$) in Model B; (8) is based on the number of deaths for total longtime nonsmokers ($3B1$ and $3B2$) in Model C being equal to the number of deaths for longtime nonsmokers ($3B$) in Model B; and (9) is based on the linear dependence, $\sum_{j=1}^{k+1} p_t^{i,j} = 1$ for $i = 3B2$. 

(8) \[ w_2 p^{3B1,4} + (1 - w_2) p^{3B2,4} (Model C) = p^{3B4} (Model B) \]

(9) \[ p^{3B2,3B2} + p^{3B2,4} = 1 \]
### Supplementary Tables

#### Table S1: Sample Characteristics at Baseline and Follow-up

|                          | Baseline    |          | Follow-up  |          |
|--------------------------|-------------|----------|------------|----------|
|                          | N           | Percent  | N          | Percent  |
| Total sample             | 164,597     | 100%     | 100,290    | 100%     |
| Age, Mean (SD)           |             |          |            |          |
| 65-74                    | 87,972      | 53.4%    | 47,929     | 47.8%    |
| 75-84                    | 55,676      | 33.8%    | 39,337     | 39.2%    |
| 85-94                    | 19,313      | 11.7%    | 12,308     | 12.3%    |
| 95+                      | 1,636       | 1.0%     | 716        | 0.7%     |
| Female                   | 95,115      | 57.8%    | 58,519     | 58.4%    |
| Race/ethnicity           |             |          |            |          |
| White non-Hispanics      | 121,334     | 76.1%    | 77,694     | 78.2%    |
| Black non-Hispanics      | 13,031      | 8.2%     | 7,427      | 7.5%     |
| Hispanics                | 15,735      | 9.9%     | 8,803      | 8.9%     |
| Other                    | 9,404       | 5.9%     | 5,408      | 5.4%     |
| Education at baseline    |             |          |            |          |
| < High school            | 34,844      | 22.0%    | 18,966     | 19.3%    |
| High school              | 55,775      | 35.3%    | 34,711     | 35.3%    |
| Some college             | 37,473      | 23.7%    | 23,399     | 23.8%    |
| College graduate         | 30,008      | 19.0%    | 21,169     | 21.5%    |
| Family income at baseline|             |          |            |          |
| < $20,000                | 48,991      | 37.7%    | 27,653     | 33.5%    |
| $20,000-50,000           | 43,118      | 33.2%    | 28,032     | 33.9%    |
| $50,000-80,000           | 27,749      | 21.4%    | 19,628     | 23.8%    |
| >=$80,000               | 9,962       | 7.7%     | 7,282      | 8.8%     |
| Do you now smoke         |             |          |            |          |
| Every day                | 10,448      | 6.6%     | 4,883      | 5.2%     |
| Some days                | 5,004       | 3.1%     | 2,524      | 2.7%     |
| Not at all               | 143,512     | 90.3%    | 86,498     | 92.1%    |
| Smoke by gender          |             |          |            |          |
| Men                      |             |          |            |          |
| Smoke every day          | 5,118       | 7.6%     | 2,274      | 5.8%     |
| Smoke some days          | 2,270       | 3.4%     | 1,205      | 3.1%     |
| Not smoke at all         | 59,671      | 89.0%    | 35,636     | 91.1%    |
| Women                    |             |          |            |          |
| Smoke every day          | 5,330       | 5.8%     | 2,609      | 4.8%     |
| Smoke some days          | 2,734       | 3.0%     | 1,319      | 2.4%     |
| Not smoke at all         | 83,841      | 91.2%    | 50,862     | 92.8%    |
Table S2: Standard Error of Estimates in Figure 2

| Age (x) | Percent quitting every day | Percent quitting some day | Percent successful quitting every day | Percent successful quitting some day | Percent Relapse |
|---------|----------------------------|---------------------------|--------------------------------------|-------------------------------------|-----------------|
| 65      | 1.5%                       | 1.5%                      | 1.5%                                 | 1.5%                                | 1.6%            |
| 67      | 1.5%                       | 1.5%                      | 1.4%                                 | 1.5%                                | 2.1%            |
| 69      | 1.6%                       | 1.7%                      | 1.4%                                 | 1.7%                                | 2.0%            |
| 71      | 1.6%                       | 1.9%                      | 1.3%                                 | 1.7%                                | 2.1%            |
| 73      | 1.7%                       | 2.0%                      | 1.3%                                 | 1.8%                                | 2.2%            |
| 75      | 1.8%                       | 2.2%                      | 1.3%                                 | 1.8%                                | 2.3%            |
| 77      | 1.8%                       | 2.3%                      | 1.2%                                 | 1.7%                                | 2.5%            |
| 79      | 1.9%                       | 2.4%                      | 1.2%                                 | 1.6%                                | 2.6%            |
| 81      | 2.0%                       | 2.5%                      | 1.2%                                 | 1.6%                                | 2.8%            |
| 83      | 2.1%                       | 2.6%                      | 1.3%                                 | 1.7%                                | 2.9%            |
| 85      | 2.2%                       | 2.7%                      | 1.4%                                 | 1.8%                                | 3.1%            |
| 87      | 2.3%                       | 3.0%                      | 1.5%                                 | 2.1%                                | 3.3%            |
| 89      | 2.4%                       | 3.3%                      | 1.7%                                 | 2.5%                                | 3.6%            |
| 91      | 2.5%                       | 3.8%                      | 1.9%                                 | 3.1%                                | 3.9%            |
| 93      | 2.6%                       | 4.6%                      | 2.1%                                 | 3.9%                                | 4.3%            |
| 95      | 2.8%                       | 5.8%                      | 2.3%                                 | 5.2%                                | 4.6%            |
Table S3: Probabilities of Quitting, Successful Quitting, and Relapse at Ages 65-95 Years, by Sex

| Age (x) | Probability of quitting daily smokers | Probability of quitting some days smokers | Probability of successful quitting daily smokers | Probability of successful quitting some days smokers | Probability of relapse |
|---------|--------------------------------------|------------------------------------------|-----------------------------------------------|-------------------------------------------------|-----------------------|
| Men     |                                      |                                          |                                               |                                                 |                       |
| 65      | 59.4%                                | 68.4%                                    | 26.4%                                         | 32.1%                                           | 57.9%                 |
| 67      | 56.6%                                | 66.6%                                    | 23.9%                                         | 30.1%                                           | 50.0%                 |
| 69      | 53.4%                                | 64.7%                                    | 20.5%                                         | 26.8%                                           | 45.8%                 |
| 71      | 50.1%                                | 62.7%                                    | 16.8%                                         | 22.9%                                           | 44.4%                 |
| 73      | 46.7%                                | 60.7%                                    | 12.9%                                         | 18.5%                                           | 44.8%                 |
| 75      | 43.5%                                | 58.7%                                    | 9.4%                                          | 14.0%                                           | 46.4%                 |
| 77      | 40.5%                                | 56.4%                                    | 6.5%                                          | 10.0%                                           | 49.3%                 |
| 79      | 37.6%                                | 53.9%                                    | 4.5%                                          | 6.9%                                            | 52.7%                 |
| 81      | 35.0%                                | 51.3%                                    | 3.5%                                          | 5.1%                                            | 56.8%                 |
| 83      | 32.9%                                | 48.3%                                    | 3.4%                                          | 4.7%                                            | 60.3%                 |
| 85      | 31.5%                                | 44.5%                                    | 3.8%                                          | 5.1%                                            | 62.3%                 |
| 87      | 30.3%                                | 40.9%                                    | 4.2%                                          | 5.6%                                            | 63.0%                 |
| 89      | 29.7%                                | 37.0%                                    | 4.3%                                          | 5.2%                                            | 61.2%                 |
| 91      | 30.1%                                | 32.7%                                    | 4.9%                                          | 5.1%                                            | 56.3%                 |
| 93      | 31.0%                                | 28.2%                                    | 5.8%                                          | 5.1%                                            | 48.8%                 |
| 95      | 32.5%                                | 24.3%                                    | 7.0%                                          | 5.1%                                            | 38.7%                 |
| Women   |                                      |                                          |                                               |                                                 |                       |
| 65      | 63.1%                                | 69.1%                                    | 36.0%                                         | 40.9%                                           | 47.7%                 |
| 67      | 59.0%                                | 67.3%                                    | 32.0%                                         | 38.4%                                           | 42.0%                 |
| 69      | 55.2%                                | 64.8%                                    | 27.9%                                         | 34.9%                                           | 39.1%                 |
| 71      | 51.5%                                | 61.7%                                    | 24.0%                                         | 30.7%                                           | 39.0%                 |
| 73      | 47.7%                                | 58.1%                                    | 20.2%                                         | 26.2%                                           | 40.3%                 |
| 75      | 43.7%                                | 54.2%                                    | 16.7%                                         | 21.8%                                           | 43.0%                 |
| 77      | 39.4%                                | 50.3%                                    | 13.4%                                         | 17.9%                                           | 46.5%                 |
| 79      | 34.7%                                | 46.5%                                    | 10.7%                                         | 14.7%                                           | 50.3%                 |
| 81      | 29.7%                                | 43.0%                                    | 8.6%                                          | 12.3%                                           | 54.0%                 |
| 83      | 24.0%                                | 40.3%                                    | 6.9%                                          | 11.2%                                           | 56.4%                 |
| 85      | 18.2%                                | 38.6%                                    | 5.6%                                          | 11.1%                                           | 56.6%                 |
| 87      | 12.6%                                | 38.1%                                    | 4.3%                                          | 12.1%                                           | 53.6%                 |
| 89      | 7.8%                                 | 38.9%                                    | 2.9%                                          | 14.3%                                           | 47.7%                 |
| 91      | 4.3%                                 | 41.3%                                    | 1.8%                                          | 17.2%                                           | 38.8%                 |
| 93      | 2.0%                                 | 45.8%                                    | 0.9%                                          | 20.6%                                           | 28.8%                 |
| 95      | 0.8%                                 | 52.6%                                    | 0.3%                                          | 23.8%                                           | 20.0%                 |
Table S4: Standard Error of Estimates in Figure 2

| Age (x) | Smokers | None smokers | Quitting vs. not quitting | Non-smokers vs. smokers |
|---------|---------|--------------|---------------------------|-------------------------|
|         | daily   | some days    | All smokers               | Recent¹                  | Long time²               | All non-smokers           |                           |
| 65      | 0.29    | 0.29         | 0.29                      | 0.30                    | 0.27                     | 0.52                      | 0.42                      | 0.59                     |
| 67      | 0.27    | 0.27         | 0.27                      | 0.28                    | 0.26                     | 0.51                      | 0.39                      | 0.57                     |
| 69      | 0.26    | 0.26         | 0.26                      | 0.27                    | 0.25                     | 0.49                      | 0.37                      | 0.56                     |
| 71      | 0.24    | 0.24         | 0.24                      | 0.25                    | 0.24                     | 0.48                      | 0.35                      | 0.54                     |
| 73      | 0.22    | 0.22         | 0.22                      | 0.23                    | 0.22                     | 0.47                      | 0.32                      | 0.52                     |
| 75      | 0.21    | 0.21         | 0.21                      | 0.22                    | 0.21                     | 0.46                      | 0.30                      | 0.50                     |
| 77      | 0.19    | 0.19         | 0.19                      | 0.20                    | 0.20                     | 0.44                      | 0.28                      | 0.48                     |
| 79      | 0.18    | 0.18         | 0.18                      | 0.19                    | 0.18                     | 0.43                      | 0.26                      | 0.46                     |
| 81      | 0.17    | 0.17         | 0.17                      | 0.17                    | 0.17                     | 0.41                      | 0.24                      | 0.44                     |
| 83      | 0.15    | 0.15         | 0.15                      | 0.16                    | 0.15                     | 0.39                      | 0.22                      | 0.42                     |
| 85      | 0.14    | 0.14         | 0.14                      | 0.14                    | 0.14                     | 0.37                      | 0.20                      | 0.40                     |
| 87      | 0.13    | 0.13         | 0.13                      | 0.13                    | 0.13                     | 0.36                      | 0.19                      | 0.38                     |
| 89      | 0.12    | 0.13         | 0.12                      | 0.12                    | 0.11                     | 0.34                      | 0.17                      | 0.36                     |
| 91      | 0.12    | 0.12         | 0.12                      | 0.11                    | 0.10                     | 0.32                      | 0.16                      | 0.34                     |
| 93      | 0.11    | 0.11         | 0.11                      | 0.10                    | 0.09                     | 0.30                      | 0.15                      | 0.32                     |
| 95      | 0.10    | 0.11         | 0.11                      | 0.10                    | 0.08                     | 0.29                      | 0.14                      | 0.30                     |

¹: quit less than 2 years  
²: never smoke or quit ≥ 2 years  
³: difference between recent non-smokers and smokers  
⁴: difference between all non-smokers and all smokers
Table S5: Life Expectancy by Initial Smoking Status at Ages 65-95 Years, by Sex

| Age (x) | Current smokers | Not smoking at all | Quitting vs. not quitting | Non-smokers vs. smokers |
|---------|-----------------|-------------------|--------------------------|------------------------|
|         | Daily smokers   | Some days smokers | All smokers              | Long time² | All non-smokers |                 |               |
| Men     |                 |                   |                          |           |                |                 |               |
| 65      | 14.8            | 15.2              | 14.9                     | 15.1      | 18.7           | 18.6           | 0.2*          | 3.7*        |
| 67      | 13.4            | 14.0              | 13.6                     | 14.5      | 17.2           | 17.1           | 0.9*          | 3.5*        |
| 69      | 12.0            | 12.8              | 12.2                     | 13.4      | 15.7           | 15.6           | 1.2*          | 3.3*        |
| 71      | 10.8            | 11.6              | 11.0                     | 12.2      | 14.2           | 14.1           | 1.2*          | 3.1*        |
| 73      | 9.6             | 10.6              | 9.9                      | 10.9      | 12.8           | 12.7           | 1.0*          | 2.8*        |
| 75      | 8.7             | 9.6               | 9.0                      | 9.6       | 11.4           | 11.4           | 0.7*          | 2.4*        |
| 77      | 7.8             | 8.7               | 8.1                      | 8.4       | 10.2           | 10.1           | 0.3*          | 2.1*        |
| 79      | 7.0             | 7.9               | 7.3                      | 7.2       | 9.0            | 9.0            | -0.1          | 1.6*        |
| 81      | 6.4             | 7.1               | 6.6                      | 6.2       | 7.9            | 7.9            | -0.4          | 1.2*        |
| 83      | 5.8             | 6.4               | 6.0                      | 5.5       | 6.9            | 6.9            | -0.5          | 0.8*        |
| 85      | 5.3             | 5.7               | 5.4                      | 4.9       | 6.0            | 5.9            | -0.5          | 0.5*        |
| 87      | 4.7             | 5.0               | 4.8                      | 4.6       | 5.1            | 5.1            | -0.2          | 0.3         |
| 89      | 4.2             | 4.2               | 4.2                      | 4.2       | 4.4            | 4.4            | 0.0           | 0.2         |
| 91      | 3.8             | 3.4               | 3.6                      | 3.6       | 3.8            | 3.8            | -0.1          | 0.2         |
| 93      | 3.4             | 2.8               | 3.1                      | 3.0       | 3.3            | 3.3            | -0.1          | 0.2         |
| 95      | 3.0             | 2.2               | 2.7                      | 2.6       | 2.9            | 2.9            | -0.1          | 0.2         |
| Women   |                 |                   |                          |           |                |                 |               |
| 65      | 17.2            | 17.4              | 17.2                     | 18.7      | 21.0           | 21.0           | 1.5*          | 3.7*        |
| 67      | 15.6            | 15.9              | 15.7                     | 17.3      | 19.4           | 19.3           | 1.7*          | 3.7*        |
| 69      | 14.0            | 14.4              | 14.2                     | 15.8      | 17.8           | 17.7           | 1.7*          | 3.5*        |
| 71      | 12.6            | 13.0              | 12.7                     | 14.3      | 16.2           | 16.1           | 1.6*          | 3.4*        |
| 73      | 11.3            | 11.6              | 11.4                     | 12.8      | 14.7           | 14.6           | 1.4*          | 3.2*        |
| 75      | 10.1            | 10.4              | 10.2                     | 11.4      | 13.2           | 13.2           | 1.2*          | 3.0*        |
| 77      | 9.0             | 9.2               | 9.1                      | 10.0      | 11.8           | 11.8           | 1.0*          | 2.7*        |
| 79      | 8.0             | 8.1               | 8.1                      | 8.8       | 10.5           | 10.4           | 0.7*          | 2.4*        |
| 81      | 7.2             | 7.2               | 7.2                      | 7.7       | 9.2            | 9.2            | 0.5*          | 2.0*        |
| 83      | 6.4             | 6.4               | 6.4                      | 6.8       | 8.1            | 8.1            | 0.3*          | 1.7*        |
| 85      | 5.8             | 5.7               | 5.7                      | 6.0       | 7.0            | 7.0            | 0.2*          | 1.3*        |
| 87      | 5.2             | 5.1               | 5.2                      | 5.3       | 6.1            | 6.1            | 0.2*          | 0.9*        |
| 89      | 4.7             | 4.6               | 4.7                      | 4.8       | 5.2            | 5.2            | 0.1           | 0.5*        |
| 91      | 4.3             | 4.2               | 4.3                      | 4.3       | 4.5            | 4.5            | 0.0           | 0.2*        |
| 93      | 3.9             | 3.9               | 3.9                      | 3.9       | 3.9            | 3.9            | 0.0           | -0.1        |
| 95      | 3.6             | 3.6               | 3.6                      | 3.4       | 3.3            | 3.3            | -0.2          | -0.3        |

¹: quit less than 2 years. ²: never smoke or quit ≥ 2 years. ³: difference between recent non-smokers and smokers. ⁴: difference between all non-smokers and all smokers. *: p < 0.05 for testing for difference between 2 groups.
# STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of cohort studies

| Section/Topic          | Item # | Recommendation                                                                 | Reported on page # |
|------------------------|--------|--------------------------------------------------------------------------------|--------------------|
| **Title and abstract** | 1      | (a) Indicate the study's design with a commonly used term in the title or the abstract | 2                  |
|                        | 1      | (b) Provide in the abstract an informative and balanced summary of what was done and what was found | 2                  |
| **Introduction**       | 2      | Explain the scientific background and rationale for the investigation being reported | 4-5                |
| **Objectives**         | 3      | State specific objectives, including any prespecified hypotheses                   | 5                  |
| **Methods**            | 4      | Present key elements of study design early in the paper                            | 5-6                |
| Study design           | 4      | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection | 6                  |
| Setting                | 5      | (a) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up | 6                  |
|                        | 5      | (b) For matched studies, give matching criteria and number of exposed and unexposed | n/a                |
| Participants           | 6      | (a) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up | 6                  |
|                        | 6      | (b) For matched studies, give matching criteria and number of exposed and unexposed | n/a                |
| Variables              | 7      | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable | 6-7                |
| Data sources/measurement| 8*     | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group | 6-7                |
| Bias                   | 9      | Describe any efforts to address potential sources of bias                           | 9-10               |
| Study size             | 10     | Explain how the study size was arrived at                                          | n/a                |
| Quantitative variables | 11     | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why | 6-7                |
| Statistical methods    | 12     | (a) Describe all statistical methods, including those used to control for confounding | 7-10, 20-23        |
|                        | 12     | (b) Describe any methods used to examine subgroups and interactions                | n/a                |
|                        | 12     | (c) Explain how missing data were addressed                                         | 6,25               |
|                        | 12     | (d) If applicable, explain how loss to follow-up was addressed                      | 6,25               |
|                        | 12     | (e) Describe any sensitivity analyses                                              | 9-10               |

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| Topic                      | Item | Description                                                                                                                                                                                                                                                                                                                                 | Page |
|----------------------------|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| Participants               | 13*  | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed                                                                                                                                                | 6    |
|                            |      | (b) Give reasons for non-participation at each stage                                                                                                                                                                                                                                                                                         | 6    |
|                            |      | (c) Consider use of a flow diagram                                                                                                                                                                                                                                                                                                         | 7-10 | Fig1 |
| Descriptive data           | 14*  | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders                                                                                                                                                                                                 | 11   |
|                            |      | (b) Indicate number of participants with missing data for each variable of interest                                                                                                                                                                                                                                                          | 6    |
|                            |      | (c) Summarise follow-up time (eg, average and total amount)                                                                                                                                                                                                                                                                               | 6    |
| Outcome data               | 15*  | Report numbers of outcome events or summary measures over time                                                                                                                                                                                                                                                                           | 6,11-13 |
| Main results               | 16   | (a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included                                                                                                  | 11-13, S2,S4 |
|                            |      | (b) Report category boundaries when continuous variables were categorized                                                                                                                                                                                                       | n/a  |
|                            |      | (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period                                                                                                                                                                 | 11-12 |
| Other analyses             | 17   | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses                                                                                                                                                                               | 14-15 |
| Discussion                 |      |                                                                                                                                                                                                                                                                                                                                       |      |
| Key results                | 18   | Summarise key results with reference to study objectives                                                                                                                                                                                                                      | 16   |
| Limitations                |      |                                                                                                                                                                                                                                                                                                                                       |      |
| Interpretation             | 20   | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence                                                                                                               | 17-18 |
| Generalisability           | 21   | Discuss the generalisability (external validity) of the study results                                                                                                                                                                                                       | 17   |
| Other information          |      |                                                                                                                                                                                                                                                                                                                                       |      |
| Funding                    | 22   | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based                                                                                                                                                      | 19   |

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.
Use of a Microsimulation Method for Assessing Dynamics of Smoking Status and Gains in Life Expectancy after Quitting in a Longitudinal Cohort of U.S. Older Adults

| **Journal** | BMJ Open |
|-------------|-----------|
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Use of a Microsimulation Method for Assessing Dynamics of Smoking Status and Gains in Life Expectancy after Quitting in a Longitudinal Cohort of U.S. Older Adults

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Appendix: Estimation of Transition Probabilities

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Abstract:

Objectives: Previous studies were unable to estimate the dynamics of smoking status in the U.S. elderly general population, and no study has assessed the benefit of quitting in terms of resultant gains in life expectancy. We proposed a novel method to estimate the percent of quitting in remaining lifetime, successful quitting, and relapse, as well as life expectancy by participants’ baseline smoking status.

Design: Longitudinal cohort.

Setting: U.S. community-dwelling population.

Participants: Respondents from the Medicare Health Outcome Survey Cohort 15 (baseline 2012, follow-up 2014). We included respondents who were aged ≥ 65 years and alive at the baseline and participated in the baseline survey (N=164,597).

Primary and secondary outcome measures: attempt quitting, successful quitting, relapse rates, and life expectancy by smoking status at age 65 to 95 years.

Results: Among 65-year old daily smokers, 61% would attempt to quit during their remaining lifetime, and 31% would quit successfully. Among 65-year old some days smokers, 69% would attempt to quit during their remaining lifetime, and 37% would quit successfully. Among 65-year old recent ex-smokers, 53% would relapse. Life expectancy at age 65 years was 20.0 (SE=0.27), 17.2 (SE=0.30), 16.2 (SE=0.29) and 15.9 (SE=0.29) years for long time non-smokers, recent ex-smokers, some days smokers, and daily smokers, respectively. Although recent ex-smokers had a higher 2-year mortality than current smokers, those who quit up to 77 years (77 for men and 87 years for women) had a significantly longer (p<0.05) life expectancy. Sensitivity analysis demonstrated that the model assumptions had a relatively small impact on estimates with a maximum relative bias less than 7%.

Conclusions: This study provides detailed information regarding the dynamics of smoking status in an understudied and growing population and demonstrates the benefit of smoking cessation on life expectancy. Future research should focus on understanding specific predictors of smoking cessation.

Keywords: smoking cessation, relapse, microsimulation, multistate model
Strengths and limitations of this study

- The large sample size of this study enables us to obtain estimates, with good reliability, at each of the 2-year age intervals from age 65 years to 95 years.

- Our method relied on the assumption that all relapses occurred within 2 years of abstinence and older longtime non-smokers do not initiate smoking or experience relapse.

- We conducted extensive sensitivity analyses that demonstrate that the impact of the main model assumption on all estimates was small.

- This analysis did not examine factors (other than age and gender) that affected quitting and relapse or the reasons for quitting and relapse.
Introduction

In the United States, smoking is the leading cause of preventable death.[1] Yet, despite substantial evidence that older persons benefit from quitting smoking in terms of both morbidity and mortality, research on smoking cessation tends to focus on younger adults.[2,3] Older adults differ from younger adults with regard to smoking prevalence, quit attempts, and relapse.[3,4] Findings from nationwide surveys of the U.S. general population indicate that the smoking prevalence is lower among older adults than among younger adults.[3,5-7] As an example, based on the 2016 National Health Interview Survey (NHIS), 8.8% of persons aged 65 years and older were current smokers compared to 17.1% of persons aged 18 to 64 years.[7] However, compared to younger smokers, older smokers are less likely to attempt quitting in the preceding 12 months.[6] Regarding the impact of smoking on life expectancy, using data from the 2009 Behavioral Risk Factor Surveillance System (BRFSS) and the NHIS, life expectancy at age 18 was estimated to be 62.5 years for non-smokers (never or former smokers) and 53.6 years for current smokers, resulting in an average loss of 9.0 years to smoking for 18-year old smokers.[8]

Previous investigations used data from nationwide, population-based, cross-sectional surveys that relied on retrospective assessments to ascertain dynamics of smoking, such as attempts to quit, successful quitting, and smoking relapse.[5-7,9-10] These assessments were based on the following four questions from the NHIS, the National Health and Nutrition Examination Survey (NHANES), and the BRFSS: (1) “Have you smoked at least 100 cigarettes in your entire life?” (2) “Do you now smoke cigarettes every day, some days, or not at all?” (3) “During the past 12 months, have you stopped smoking for longer than a day because you were trying to quit smoking?” and (4) “How long has it been since you quit smoking cigarettes?” For example, respondents who answered “Yes” to question (3) were classified as having a recent quit attempt.[6,7] Respondents who answered “Every day” or “Some days” to question (2) and “Yes” to question (3) were classified as having a smoking relapse.[5] Successful quitting was measured by calculating the quit ratio which is the ratio of former smokers, those who answer “Yes” to question (1) and “not at all” to question (2), to ever smokers, those who answer “Yes” to question (1).[6,7,9] However, this approach cannot provide estimates of the percent of quitting
and successful quitting for current smokers and percent of relapse for ex-smokers because the appropriate
denominators for the calculation of percentages cannot be determined. In addition, estimates based on these
questions are subject to recall bias as well as selective survival bias.

It is also difficult to quantify the impact of smoking on mortality and the benefits of quitting in terms of
years of life lost due to smoking and gains in life years after quitting.[11] To our knowledge, no study has
estimated gains in life expectancy after quitting in the older U.S. general population. A number of different
reasons exist as to why this is not a straightforward analysis. For example, health risks, in the form of chronic
diseases and premature death, may become clinically manifest only after many years of smoking. Similarly, the
impact of quitting, in the form of a decrease in mortality, may not be apparent until many years after having
quit. Conversely, being in poor health or having chronic conditions usually is the reason to quit smoking.[12,13]
and, therefore, recent ex-smokers might have a higher mortality several years after quitting as compared to
current smokers.[11] Additionally, smoking status is not a permanent state and may change throughout the
lifespan. A person may attempt to quit and relapse many times.[14,15] Because of these potential scenarios,
estimating life expectancy for individuals based on their baseline smoking status should account for transitions
between different smoking statuses during their remaining lifetime.[16] However, previous analyses of losses in
life expectancy due to smoking assumed that smoking status would be unchanged throughout the remainder of
expected lifetime for both smokers and non-smokers, and, therefore, this assumption would likely overestimate
years of life losses to smoking.[8,17,18]

Ideally, these estimates should be from a large prospective cohort that is representative of the general
population and records participants’ smoking status on a regular basis over many decades until death. Due to the
high data requirements, we developed a novel method that used a single current smoking status question,
Question (2) above, from a large, cohort sample of U.S. elderly population with a relatively short follow-up
interval. The present study describes and applies this method to estimate dynamics of smoking status of U.S.
older adults aged 65 years or older using a large, national representative legacy dataset. There are two specific aims: (1) to estimate the percentages of quitting during the remaining lifetime and successful quitting among current smokers and the percentages of relapse among recent ex-smokers (defined as less than 2 years of abstinence); and (2) to estimate life expectancy at age 65 to 95 years by respondents’ baseline smoking status. We examined whether life expectancy increased after quitting. Finally, to assess the validity of our estimates, we conducted a sensitivity analysis by examining the impact of the model assumptions on our estimates.

Methods

In this study, the term “quitting” refers to a participant who reported smoking previously and does not currently smoke. “Successful quitting” refers to an ex-smoker who has been abstinent from smoking for at least two years and remains a nonsmoker until death. “Relapse” refers to a person who reported not smoking previously and is smoking now.

Data and measures: The data were obtained from the Medicare Health Outcome Survey (HOS), a nationwide survey of Medicare beneficiaries.[19] Each year, the HOS randomly selects a cohort of Medicare beneficiaries who voluntarily enrolled in Medicare Advantage private health plans. The selected individuals who completed a baseline survey are resurveyed two years later. We used the Medicare HOS Cohort 15 whose baseline data were collected in 2012 and follow-up data were collected in 2014. This dataset contains date of death if death occurred by January 31, 2015. We included respondents who were aged 65 years or older and alive at the baseline and participated in the baseline survey. The total sample was 164,597 (Supplementary File, Table S1). Among them, 100,290 (61%) were alive at follow-up and completed the follow-up survey, and 64,597 (39%) did not participate in the follow-up survey, including 26,111 (16%) who died and 38,196 (23%) who were alive, but did not complete the survey. An additional 88 participants died after completing the follow-up survey. The average time from the baseline to follow-up survey was 730.3 days (Interquartile range, IRQ=700-730 days). The average follow-up time (from baseline to death or to January 31, 2015) was 901.1 days (IRQ= 932-1,099 days).
The Medicare HOS includes only one question on current smoking status. The survey did not ask respondents about their life time smoking status nor recent quit attempt. At both baseline and follow-up surveys, the HOS asks respondents “Do you now smoke every day, some days, or not at all?”[20] We used this question to classify respondents as daily smokers, occasional smokers, and non-smokers. Of the 164,597 individuals who participated the baseline survey, 158,964 (96.6%) answered the smoking question; of the 100,290 individuals who participated in the follow-up survey, 93,905 (93.6%) answered the smoking question (Table S1).

**Statistical Analysis:** We proposed a smoking transition model that classified non-smokers into recent ex-smokers and longtime non-smokers based on their answers to the current smoking question at the baseline and two years later. The microsimulation method was used to project individuals’ future smoking status until death through a sequence of independent trials in a first order Markov process based on multi-state models and to estimate their expected number of remaining life years (i.e., life expectancy).[21,22]

Multi-state models were used to estimate probabilities of transferring between different smoking states.[16,22] Because the baseline and follow-up surveys were 2 years apart, we constructed a multi-state model in 2-year age intervals, at ages 65, 67, … years. To illustrate the method, we describe a Markov process with \( k \) transient states (\( s_1, s_2, ..., s_k \)) for \( k \) levels of smoking status and one absorbing state (\( s_{k+1} \)) for dead. Let \( p_{t}^{i,j} = \Pr(s_{t+2} = j|s_t = i) \) be the transition probability from state \( s_i \) at age \( t \) to state \( s_j \) at age \( t + 2 \). These transition probabilities satisfy linear dependence: \( \sum_{j=1}^{k+1} p_{t}^{i,j} = 1 \) for all \( i \). Because \( s_{k+1} \) is the absorbing state, \( p_{t}^{k+1,i} = 0 \) for \( i \leq k \) and \( p_{t}^{k+1,k+1} = 1 \).

Using the current smoking status question, we applied a multi-state model with 3 transient states, \( s_1, s_2, s_3 \) for “smoking daily”, “smoking occasionally”, and “non-smoking”, and one absorbing state (\( s_4 \)) for dead (Figure 1, Model A). This model has a transition matrix
\[ P_x = [p^i_j] = \begin{bmatrix}
p_1^{11} & p_1^{12} & p_1^{13} & p_1^{14} \\
p_2^{21} & p_2^{22} & p_2^{23} & p_2^{24} \\
p_3^{31} & p_3^{32} & p_3^{33} & p_3^{34} \\
0 & 0 & 0 & 1
\end{bmatrix}. \]

For example, \( p_1^{13} \) and \( p_2^{23} \) are probabilities of quitting for daily smokers, and some days smokers, respectively; \( p_3^{31} \) and \( p_3^{32} \) are probabilities of relapse for daily smokers and some days smokers, respectively; and \( p_1^{14}, p_2^{24}, \) and \( p_3^{34} \) are probabilities of dying for daily smokers, some days smokers, and non-smokers.

In Model A, the “non-smoking” state includes recent ex-smokers, longtime ex-smokers, and never smokers. This model assumes the same relapse and mortality rates for them. Although recent ex-smokers compose a very small proportion of the “non-smoking” group, nearly all relapses are from those with less than 2 years of abstinence.[17,23,24] Also, recent ex-smokers might have a higher mortality rate than longtime ex-smokers and never smokers. Therefore, Model A may be invalid. The main problem is that the Medicare HOS did not ask respondents about their lifetime smoking status. Therefore, we were unable to separate non-smokers into never smokers and former smokers.

To solve this problem, we partitioned the “non-smoking” state, \( s_3 \), into two mutually exclusive states: \( s_3A \) for “recent non-smoking” and \( s_3B \) for “longtime non-smoking” (Figure 1, Model B). Because never smokers and longtime ex-smokers would be unlikely to start smoking at an advanced age of 65 years or older and nearly all relapses (about 99%) were within 2 years of abstinence,[23-26] we assumed all relapses occurred within 2 years of abstinence and older longtime non-smokers do not initiate smoking or experience relapse, i.e., \( p_1^{3B,1} = p_2^{3B,1} = 0. \) Based on this assumption, Model B has a transition probability matrix

\[ P_x = [p^i_j] = \begin{bmatrix}
p_1^{11} & p_1^{12} & p_1^{13} & 0 & 0 & p_1^{14} \\
p_2^{21} & p_2^{22} & p_2^{23} & 0 & 0 & p_2^{24} \\
p_3^{3A,1} & p_3^{3A,2} & 0 & p_3^{3A,3B} & 0 & p_3^{3A,4} \\
0 & 0 & 0 & p_3^{3B,3B} & 0 & p_3^{3B,4} \\
0 & 0 & 0 & 0 & 1
\end{bmatrix}. \]
For Model B, the recent non-smoking measure was operationalized as smoking at baseline and not smoking at follow-up. The longtime non-smoking measure was operationalized as not smoking at both baseline and follow-up.

All transition probabilities \( p_{i,j}^t, i = 1,2,3, \) and \( j = 1,2,3,4 \) in Model A at a given age between states \( s_1, s_2, s_3 \) and \( s_4 \) can be estimated from the HOS data (details are in Appendix A1).[16] For Model B, six transition probabilities \( p^{1,1}, p^{1,2}, p^{1,4}, p^{2,1}, p^{2,2}, \) and \( p^{2,4} \) are available from Model A directly. The remaining eight transition probabilities, \( p^{13A}, p^{13A_1}, p^{3A_1}, p^{3A_2}, p^{3B_3}, p^{3B_4}, p^{3A_4}, \) and \( p^{3B_4} \), can be estimated based on assumptions of Model B (details are in Appendix A2).

**Microsimulations:** We projected the future smoking status of each individual in a synthetic cohort of persons using the microsimulation method.[21,22] For an age cohort of 1,000,000 individuals of a given initial state \( s_i \) \((i = 1, 2, 3A, 3B)\) at starting age \( x \), using the estimated transition probabilities of Model B, we simulated each individual’s smoking state at age \( x + 2, x + 4, \) ... iteratively until all individuals died. Percent of quitting in the remaining lifetime was estimated as the proportion ever entering the recent non-smoking state \( s_{3A} \) for a cohort of current smokers \( (s_1 \) or \( s_2 \)) at the starting age \( x \). Percent of successful quitting was estimated as the proportion entering the longtime non-smoking state \( s_{3B} \) for a cohort of current smokers. Percent of relapse was estimated as the proportion entering the current smoking states \( (s_1 \) or \( s_2 \)) for a cohort of recent ex-smokers \( s_{3A} \).

Life expectancy is estimated as the average number of years from the starting age to age of death for a cohort of individuals in a given initial state \( s_i(i = 1, 2, 3A, 3B) \) at starting age \( x \). If death occurred during the age interval from \( x + 2k \) to \( x + 2(k + 1) \), average years to death is \( e_x = 2k + 2a \), where \( a \) is the proportion of time lived in the 2-year age interval for persons who died during the interval. Assuming a constant mortality rate during an age interval, it can be shown that \( a = 1 - \frac{1}{Ln(1 - p)} - \frac{1}{p} \), where \( P = p^{i,4}(i = 1, 2, 3A, 3B) \) is probability of death during the age interval. When \( P \) is small and close to 0, \( a \approx 0.5 \), otherwise, \( a < 0.5 \).
The standard errors of all estimates were derived from microsimulation and includes the random variation of individuals’ outcomes conditional to transition probabilities and imprecision of the estimated transition probabilities (i.e., first and second order Monte Carlo uncertainty).\[22,27\]

**Sensitivity Analysis:** Our estimates relied on the assumption that all relapses occurred within 2 years of abstinence and no relapse for longtime non-smokers. This assumption may lead to underestimation of successful quitting. To assess the impact of this assumption, we conducted a sensitivity analysis by examining a model that allows relapse for non-smokers who had not smoked in the past 2+ years (Figure 1, Model C). Because relapse rates decreased with years of abstinence,\[5,25,26,28\] we assumed that all relapses for those who had not smoked in the past 2+ years occurred between years 2 and 4 of abstinence and there was no relapse after 4+ years of abstinence. Extending from Model B, and let states $s_{3A}$, $s_{3B1}$, and $s_{3B2}$ be non-smoking for $< 2$ years, 2-4 years, and $\geq 4$ years, respectively, the Model C has a transition matrix

$$P_x = \begin{bmatrix} p_{1,1} & p_{1,2} & p_{1,3A} & 0 & 0 & p_{1,4} \\ p_{2,1} & p_{2,2} & p_{2,3A} & 0 & 0 & p_{2,4} \\ p_{3A,1} & p_{3A,2} & 0 & p_{3A,3B1} & 0 & p_{3A,4} \\ p_{3B1,1} & p_{3B1,2} & 0 & 0 & p_{3B1,3B2} & p_{3B1,4} \\ 0 & 0 & 0 & 0 & p_{3B2,3B2} & p_{3B2,4} \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}.$$  

To estimate transition probabilities of Model C, we made following two assumptions:

1. We assumed the probabilities of transferring from state $s_{3B1}$ to states $s_1$ and $s_2$ are in the form of $p_{3B1,1} = RR * p_{3A,1}$ and $p_{3B1,2} = RR * p_{3A,2}$, respectively, where RR is the risk ratio of relapse for state $s_{3B1}$ relative to state $s_{3A}$. Data from previous studies showed that the relapse rate for those with 2+ years of abstinence was between 5% and 13% of that for those with $\leq 2$ years of abstinence.\[23-26,28\] We used RR=0.05 (scenario A) and 0.15 (scenario B) as lower bound and upper bound, respectively.

2. We expected that the mortality rates for those who had quit for between 2-4 years should be between the mortality rates for those who had quit for $>4$ years and those who quit $\leq 2$ years of the same age.\[11\] i.e.,
\[ p^{A,4} \geq p^{B,4} \geq p^{B,2,4} \]. We used \( p^{B,1,4} = p^{A,4} \) (scenario 1) and \( p^{B,1,4} = p^{A,4} \) (scenario 2) as lower bound and upper bound, respectively.

We estimated models with model parameters under four different scenarios with the combination of these scenarios: A-1, A-2, B-1, and B-2.

Nine transition probabilities (\( p^{1,1} \), \( p^{1,2} \), \( p^{1,3,4} \), \( p^{1,4} \), \( p^{2,1} \), \( p^{2,2} \), \( p^{2,3,4} \), \( p^{2,4} \), and \( p^{3,4,4} \)) are from Model B directly. The remaining nine transition probabilities (\( p^{3,1,4} \), \( p^{3,2,1} \), \( p^{3,2,3,4} \), \( p^{3,1,1} \), \( p^{3,1,2} \), \( p^{3,2,3,2} \), \( p^{3,1,4} \), \( p^{3,2,3,2} \), and \( p^{3,2,4} \)) can be estimated based on Model C assumptions. Details of transition probability estimation for Model C are available in Appendix A3. We compared estimates from Model B to that from Model C.

**Patient and public involvement:** Patients and/or the public were not involved in the design, conduct, reporting, or dissemination plans of this research.

**Results**

At baseline, the average participant age was 75.1 years, with 53% of participants between 65 and 74 years old, 34% of participants between 75 and 84 years old, and 13% of participants 85 years or older (Supplementary File, Table S1). Women comprised 58% of the sample, and white, non-Hispanics 76% of the sample. About 10% participants reported currently smoking, including 6.6% daily smokers and 3.1% occasional smokers. At the follow-up survey, about 8% participants reported currently smoking, including 5.2% daily smokers and 2.7% some days smokers. Men were more likely (about 25% more) to be current smokers than women.

Table 1 presents the estimated transition probabilities for each the four smoking statuses: daily smoking, some days smoking, recent non-smoking, and longtime non-smoking. These results provide 2-year quit rates for
current smokers and 2-year relapse rates for recent quitters. As an example, for 65-year old daily smokers, 83.1% (73.0% daily and 10.1% some days) would still smoke at age 67 and 12.2% would quit; as a comparison, for a cohort of 65-year old some days smokers, at age 67 years, 75.7% (16.5% daily and 59.2% some days) would still smoke and 19.4% would quit. For 65-year old recent ex-smokers, at age 67 years, 53.2% (18.4% daily and 34.8% some days) would smoke again (relapse), and 40.5% would still abstain from smoking. These results also provide 2-year mortality by smoking status. Recent ex-smokers had the highest 2-year mortality rates, followed by daily smokers and some days smokers, and longtime non-smokers had the lowest 2-year mortality rates. For example, the 2-year mortality rates among 65-year-old persons were 6.3%, 4.8%, 5.0%, and 2.0% for the four groups, respectively.

Table 1: Transition Probabilities between Different Smoking States at Ages 65-95 Years

| Age (x) | Transfer from daily smoking ($s_1$) to | Transfer from some days smoking ($s_2$) to | Transfer from recent non-smoking ($s_{3A}$) to | Transfer from longtime non-smoking ($s_{3B}$) to |
|---------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
|         | daily smoking ($s_1$) | some days smoking ($s_2$) | recent non-smoking ($s_{3A}$) | non-smoking ($s_{3B}$) | dead ($s_4$) | daily smoking ($s_1$) | some days smoking ($s_2$) | recent non-smoking ($s_{3A}$) | non-smoking ($s_{3B}$) | dead ($s_4$) |
| 65      | 73.0% | 10.1% | 12.2% | 0% | 4.8% | 16.5% | 59.2% | 19.4% | 0% | 5.0% |
| 67      | 71.6% | 9.8%  | 12.6% | 0% | 6.0% | 16.4% | 57.2% | 20.9% | 0% | 5.4% |
| 69      | 70.2% | 9.7%  | 12.8% | 0% | 7.4% | 16.3% | 55.8% | 21.8% | 0% | 6.1% |
| 71      | 68.5% | 9.8%  | 12.6% | 0% | 9.0% | 16.2% | 54.7% | 22.1% | 0% | 7.1% |
| 73      | 66.8% | 10.1% | 12.3% | 0% | 10.8% | 16.0% | 53.8% | 22.0% | 0% | 8.2% |
| 75      | 65.2% | 10.3% | 11.9% | 0% | 12.6% | 15.7% | 53.1% | 21.7% | 0% | 9.5% |
| 77      | 63.4% | 10.4% | 11.5% | 0% | 14.7% | 15.4% | 52.1% | 21.3% | 0% | 11.2% |
| 79      | 61.6% | 10.4% | 11.1% | 0% | 16.9% | 15.0% | 50.7% | 21.0% | 0% | 13.4% |
| 81      | 60.0% | 10.1% | 10.8% | 0% | 19.1% | 14.5% | 48.9% | 20.8% | 0% | 15.8% |
| 83      | 58.2% | 9.5%  | 10.7% | 0% | 21.6% | 13.8% | 46.4% | 21.1% | 0% | 18.7% |
| 85      | 56.3% | 8.6%  | 10.8% | 0% | 24.3% | 13.1% | 42.8% | 21.9% | 0% | 22.2% |
| 87      | 54.3% | 7.3%  | 11.1% | 0% | 27.3% | 12.3% | 38.4% | 23.3% | 0% | 26.0% |
| 89      | 52.3% | 5.7%  | 11.6% | 0% | 30.4% | 11.3% | 33.1% | 25.6% | 0% | 30.1% |
| 91      | 50.2% | 4.0%  | 12.1% | 0% | 33.7% | 10.1% | 26.9% | 29.0% | 0% | 34.1% |
| 93      | 47.9% | 2.4%  | 12.4% | 0% | 37.2% | 8.7%  | 19.7% | 33.6% | 0% | 37.9% |
| 95      | 45.3% | 1.2%  | 12.3% | 0% | 41.1% | 7.3%  | 11.5% | 39.9% | 0% | 41.3% |
| Age | $s_1$ | $s_2$ | $s_{3A}$ | $s_{3B}$ | $s_4$ | $s_1$ | $s_2$ | $s_{3A}$ | $s_{3B}$ | $s_4$ |
|-----|-------|-------|---------|---------|-------|-------|-------|---------|---------|-------|
| 65  | 18.4% | 34.8% | 0%      | 40.5%   | 6.3%  | 0%    | 0%    | 0%      | 98.0%   | 2.0%  |
| 67  | 17.2% | 28.9% | 0%      | 47.0%   | 6.9%  | 0%    | 0%    | 0%      | 97.6%   | 2.4%  |
| 69  | 16.6% | 26.0% | 0%      | 49.5%   | 7.9%  | 0%    | 0%    | 0%      | 97.1%   | 2.9%  |
| 71  | 16.5% | 25.2% | 0%      | 49.1%   | 9.2%  | 0%    | 0%    | 0%      | 96.4%   | 3.6%  |
| 73  | 16.7% | 25.8% | 0%      | 46.6%   | 10.9% | 0%    | 0%    | 0%      | 95.5%   | 4.5%  |
| 75  | 17.2% | 27.5% | 0%      | 42.4%   | 12.9% | 0%    | 0%    | 0%      | 94.5%   | 5.5%  |
| 77  | 17.7% | 30.1% | 0%      | 36.7%   | 15.4% | 0%    | 0%    | 0%      | 93.1%   | 6.9%  |
| 79  | 18.1% | 33.4% | 0%      | 30.2%   | 18.3% | 0%    | 0%    | 0%      | 91.4%   | 8.6%  |
| 81  | 18.2% | 36.9% | 0%      | 23.6%   | 21.3% | 0%    | 0%    | 0%      | 89.4%   | 10.6% |
| 83  | 17.9% | 39.9% | 0%      | 17.7%   | 24.4% | 0%    | 0%    | 0%      | 86.8%   | 13.2% |
| 85  | 17.1% | 41.8% | 0%      | 13.6%   | 27.5% | 0%    | 0%    | 0%      | 83.5%   | 16.5% |
| 87  | 15.7% | 41.7% | 0%      | 12.5%   | 30.1% | 0%    | 0%    | 0%      | 79.5%   | 20.5% |
| 89  | 13.8% | 39.1% | 0%      | 15.5%   | 31.6% | 0%    | 0%    | 0%      | 75.0%   | 25.0% |
| 91  | 11.5% | 34.0% | 0%      | 22.6%   | 31.9% | 0%    | 0%    | 0%      | 69.9%   | 30.1% |
| 93  | 9.0%  | 27.1% | 0%      | 28.2%   | 35.7% | 0%    | 0%    | 0%      | 64.3%   | 35.7% |
| 95  | 6.6%  | 19.5% | 0%      | 32.4%   | 41.5% | 0%    | 0%    | 0%      | 58.5%   | 41.5% |

$s_1$: daily smoking, $s_2$: some days smoking, $s_{3A}$: recent non-smoking, $s_{3B}$: longtime non-smoking, $s_4$: dead

Figure 2 presents percentages of quitting in the remaining lifetime and successful quitting for current smokers, respectively, and percentages of relapse for recent ex-smokers. Standard errors of estimates are available in Supplementary File (Table S2). For example, among 65-year old daily smokers, 61.3% (SE=1.5%) would quit in their remaining lifetime, and 31.5% (SE=1.5%) would quit successfully. Among 65-year old recent ex-smokers, 53.2% (SE=1.6%) would relapse. The probabilities of relapse are the same regardless of how many years ago someone quit because of the model assumption, i.e., all relapses were within 2 years of quitting.

Although the percentages of quitting in the remaining lifetime were similar between men and women (Supplementary File, Table S3), women were more likely to quit smoking successfully and less likely to relapse than men.

Life expectancy at a given age by participants’ baseline smoking status are in Table 2, with standard errors in Supplementary File (Table S4). For example, life expectancy at age 65 years was 20.0 (SE=0.27), 17.2 (SE=0.30), 16.2 (SE=0.29) and 15.9 (SE=0.29) years for longtime non-smokers, recent ex-smokers, some days

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smokers, and daily smokers, respectively. Quitting between 65 and 77 years of age had a significantly (p<0.05) longer life expectancy as compared to current smokers. All non-smokers had a significantly longer life expectancy than did all current smokers between the ages of 65 to 87 years. When examined by gender (Supplementary File, Table S5), the difference in life expectancy between non-smokers and smokers was similar between men and women. However, quitting smoking contributed to slightly greater gains in life expectancy among women than men. Men benefit from quitting up to age 77 years, while women benefit from quitting up to age 87 years.

Table 2: Life Expectancy by Baseline Smoking Status at Ages 65-95 Years

| Age (x) | Smoking | | Not smoking at all | | Quitting vs. not quitting | Non-smokers vs. smokers |
|---|---|---|---|---|---|---|
| 65 | Daily | 15.9 | 16.2 | 16.0 | 17.2 | 20.0 | 19.9 | 1.2* | 3.9* |
| 67 | Some days | 14.4 | 14.9 | 14.6 | 16.0 | 18.4 | 18.3 | 1.4* | 3.8* |
| 69 | All smokers | 13.0 | 13.6 | 13.2 | 14.6 | 16.8 | 16.8 | 1.5* | 3.6* |
| 71 | Recent | 11.7 | 12.3 | 11.9 | 13.2 | 15.3 | 15.3 | 1.4* | 3.4* |
| 73 | Long time | 10.5 | 11.1 | 10.7 | 11.8 | 13.8 | 13.8 | 1.2* | 3.1* |
| 75 | All non-smokers | 9.4 | 10.0 | 9.6 | 10.5 | 12.5 | 12.4 | 0.9* | 2.8* |
| 77 | Quitting | 8.4 | 8.9 | 8.6 | 9.2 | 11.1 | 11.1 | 0.6* | 2.5* |
| 79 | vs. not quitting | 7.6 | 8.0 | 7.7 | 8.1 | 9.9 | 9.8 | 0.4 | 2.1* |
| 81 | 6.8 | 7.2 | 6.9 | 7.1 | 8.7 | 8.7 | 0.1 | 1.7* |
| 83 | 6.2 | 6.4 | 6.2 | 6.2 | 7.6 | 7.6 | 0.0 | 1.4* |
| 85 | 5.6 | 5.7 | 5.6 | 5.5 | 6.6 | 6.6 | -0.1 | 1.0* |
| 87 | 5.0 | 5.1 | 5.1 | 5.0 | 5.7 | 5.7 | -0.1 | 0.7 |
| 89 | 4.6 | 4.6 | 4.6 | 4.5 | 5.0 | 5.0 | -0.1 | 0.4 |
| 91 | 4.1 | 4.1 | 4.1 | 4.2 | 4.3 | 4.3 | 0.1 | 0.2 |
| 93 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 0.1 | 0.0 |
| 95 | 3.3 | 3.3 | 3.3 | 3.3 | 3.2 | 3.2 | 0.0 | -0.1 |

1: quit less than 2 years  
2: never smoke or quit > 2 years  
3: difference between recent non-smokers and all smokers  
4: difference between all non-smokers and all smokers  
*: p < 0.05 for testing for difference between 2 groups.

**Sensitivity Analysis Results**: Finally, we examined the impact of the model assumption (no relapse among longtime non-smokers) on our estimates by comparing estimates from Model B to estimates from Model C.
which allows relapse for non-smokers with 2+ years’ abstinence (Table 3). The model assumption had no or a very small impact on estimation of percent of quitting in the remaining lifetime, percent of relapse, and life expectancy for longtime non-smokers, as demonstrated by the similar estimates from Model B and Model C. In most scenarios, the model assumption underestimated percent of successful quitting slightly, as estimates from Model B were about 0.8% to 2.7% lower than that from Model C, with relative bias from -2.2% to -6.6%; and overestimated life expectancy slightly for current smokers and recent ex-smokers, as estimates from Model B were about 0.1-1.0 years higher than that from Model C, with relative bias from 0.4% to 5.9%.
Table 3: Sensitivity Analysis – Assess the Validity of Model Assumption

| Outcomes¹ | Model B | Model C | Bias | Relative bias |
|-----------|---------|---------|------|--------------|
|           | Scenario A-1 | Scenario A-2 | Scenario B-1 | Scenario B-2 |
|           | Scenario A-1 | Scenario A-2 | Scenario B-1 | Scenario B-2 |
|           | Scenario A-1 | Scenario A-2 | Scenario B-1 | Scenario B-2 |
|           | Scenario A-1 | Scenario A-2 | Scenario B-1 | Scenario B-2 |
| Quitting  | 61.3% | 61.2% | 61.2% | 61.2% | 0.0% | 0.0% | 0.1% | 0.0% | 0.1% | 0.1% | 0.1% | 0.1% | 0.1% | 0.1% | 0.1% |
| Daily smokers | 68.6% | 68.6% | 68.5% | 68.6% | 68.5% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Some days smokers | 31.5% | 32.2% | 32.2% | 33.7% | 33.7% | -0.8% | -0.7% | -2.2% | -2.2% | -2.3% | -2.3% | -6.6% | -6.6% | -6.6% | -6.6% |
| Successful quitting | 36.8% | 37.6% | 37.6% | 39.2% | 39.2% | -0.8% | -0.8% | -2.4% | -2.4% | -2.2% | -2.2% | -6.2% | -6.2% | -6.2% | -6.2% |
| Daily smokers | 53.2% | 53.1% | 53.1% | 52.9% | 52.9% | 0.1% | 0.1% | 0.3% | 0.3% | 0.2% | 0.2% | 0.6% | 0.6% | 0.6% | 0.6% |
| Relapse | 15.9 | 15.8 | 15.7 | 15.7 | 15.4 | 0.1 | 0.2 | 0.2 | 0.5 | 0.4% | 1.3% | 1.2% | 3.1% | 3.1% | 3.1% |
| Life expectancy | 16.2 | 16.2 | 16.0 | 16.0 | 15.7 | 0.1 | 0.2 | 0.2 | 0.6 | 0.5% | 1.5% | 1.5% | 3.6% | 3.6% | 3.6% |
| Daily smokers | 17.2 | 17.1 | 16.8 | 16.8 | 16.3 | 0.2 | 0.4 | 0.5 | 1.0 | 0.9% | 2.4% | 2.8% | 5.9% | 5.9% | 5.9% |
| Some days smokers | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1% | 0.1% | 0.1% | 0.2% | 0.2% | 0.2% |
| Recent ex-smokers² | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1% | 0.1% | 0.1% | 0.2% | 0.2% | 0.2% |
| Longtime nonsmokers³ | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1% | 0.1% | 0.1% | 0.2% | 0.2% | 0.2% |

¹: all estimates are at age 65 years
²: quit less than 2 years
³: never smoke or quit ≥ 2 years

Scenario A-1: when relapse rate for those with 2+ years of abstinence was 5% of that for those with ≤ 2 years of abstinence; and mortality rate for those who had quit for between 2-4 years equals mortality rate for those who had quit for >4 years of the same age
Scenario A-2: when relapse rate for those with 2+ years of abstinence was 5% of that for those with ≤ 2 years of abstinence; and mortality rate for those who had quit for between 2-4 years equal mortality rate for those who had quit ≤ 2 years of the same age
Scenario B-1: when relapse rate for those with 2+ years of abstinence was 15% of that for those with ≤ 2 years of abstinence; and mortality rate for those who had quit for between 2-4 years of the same age
Scenario B-2: when relapse rate for those with 2+ years of abstinence was 15% of that for those with ≤ 2 years of abstinence; and mortality rate for those who had quit for between 2-4 years equal mortality rate for those who had quit ≤ 2 years of the same age
Discussion

Summary of findings: This study provides detailed information regarding the dynamics of smoking status as well as the benefit of smoking cessation on life expectancy among U.S. older adults. Not surprisingly, we found that smoking was associated with a significantly reduced life expectancy and that gains in life expectancy could be achieved with quitting up to age 77 years (up to 77 years for men, and up to 87 years for women). These results on the impact of smoking and smoking cessation on life expectancy among older adults are the first reported in the literature and fill critical gaps in smoking cessation research. Yet, in terms of quitting, although approximately two thirds of 65-year-old smokers will attempt to quit smoking during their remaining lifetime, only about one third will be able to quit successfully, while about one in every two 65-year-old recent ex-smokers will relapse. Our estimates are consistent with previous analyses of the probability of relapse or successful quitting and the probability of quit attempts.[5-7,9,10]

As the age pyramid for the U.S. shifts, due to a greater proportion of persons aged 65 and older, investigators have sought to characterize the range of health trajectories among the elderly.[29] Because of the trend of an increasing percentage of persons 65 and over in the U.S. population, the total number of elderly persons who smoke may increase even if the prevalence of smokers is unchanged.[3] Understanding the age differences in cessation and relapse rates as well as benefit of quitting is critical, given that smoking patterns and predictors may differ between younger and older populations. According to 2017 NHIS data, recent successful cessation tends to decrease with age and is lowest among adults 65 and older.[3,30] The elderly population represent a heterogeneous group, often being categorized into different strata based on chronological and functional-age, and the dynamics of smoking may differ between young-old (65-74), middle-old (75-84), and old-old (85 and over).[31,32] The large sample size of the Medicare HOS data enables us to obtain estimates, with good reliability, at each of the 2-year age intervals from age 65 years to 95 years, and this is one of the strengths of our study.
Methodological considerations: Many previous investigations of smoking cessation and relapse in the U.S. general population relied on questions of previous quitting attempts and years since quitting from large, nationwide, cross-sectional surveys such as the NHIS, NHANES, and BRFSS.[5-7,9,10] The main weakness of this approach is the inability to calculate percent of successful quitting and relapse as well as potential recall bias and selective survival bias. Although some studies used cohort data to analyze the dynamics of smoking, the sample sizes of these studies were usually too small to provide reliable estimates.[25,33] Furthermore, these cohort studies used either clinical samples or non-representative samples of the general population.

Because lifetime smoking history is not assessed in the data, we could not examine never smokers and former smokers. Instead, we examined recent non-smokers and longtime non-smokers. We proposed a method based on the microsimulation method that constructs a synthetic cohort of participants with the same baseline smoking status by simulating each individual's future smoking status until death. This method is novel through using a single current smoking question contained in a large, cohort survey of the U.S. general elderly population with a relatively short follow-up. In this study, the smoking status is assessed and the probabilities of changing smoking status were assessed at two time points. The respondents' previous smoking status was obtained by modeling transition probabilities between different smoking status from baseline and follow-up surveys. We simulated respondents' future smoking status through a sequence of independent trials based on transition probabilities between different smoking states from multi-state models.

All transition probabilities can be estimated by assuming no smoking relapse or initiation for longtime non-smokers, which includes never smokers and former smokers who quit smoking for more than 2 years. We made this assumption based on: (1) Nearly half of older adults had never smoked before and they were very unlikely to start smoking for the first time. The smoking initiation rate decreased with age after 18 years of age.[4,34] Data from the 2003-2010 the NHANES indicate that among ever smokers aged 65 years or older, only 0.1% started smoking at age 65 years or later.[35] (2) Relapse rates would be much lower after 2+ years of abstinence. Previous studies uniformly showed that relapse rates decreased with years of abstinence.[5,23-26,28]
For example, data from 1,449 former smokers in California showed that the likelihood of relapse for those with 2+ years of abstinence was about 93% lower than that for those with less than 2 years of abstinence.[26] Additionally, our sensitivity analysis demonstrated that, for most scenarios, the impact on our estimates was small, with the maximum relative bias less than 7%.

Previous estimates of the impact of smoking on life expectancy in general population relied on the assumption that smoking status would be unchanged throughout the remaining lifetime.[8,17,18] As a result, these studies would likely overestimate years of life losses to smoking. The present study was able to account for the possible change in smoking statuses during the remaining lifetime when estimating losses in years of life expectancy to smoking and years of life gained after quitting. By doing so, our estimates were less biased. Moreover, with the application of the microsimulation method, this study was able to estimate probability of successful quitting while previous studies were unable to make such calculations.[6,7,9]

Limitations: First, because this analysis is based on a survey of Medicare beneficiaries who voluntarily enrolled in private Medicare Advantage health plans, the current sample may be younger and healthier than the overall Medicare population.[36] Second, the smoking status was based on self-reported data. However, using self-reported smoking status would be unlikely to have a large impact on our conclusions. Even if some participants underreported their smoking history, it would not overestimate quitting attempts or underestimate relapse because underreports were at both baseline and follow-up. Furthermore, underreporting would not overestimate gains in life expectancy after quitting. Third, respondents reported their current smoking status, and the difference between “smoke some days” and “not smoke at all” in question “Do you now smoke?” is not very clear. Fourth, we assumed only a single transition from baseline to follow-up, and transitions were made at the end of the time interval. This assumption can lead to underestimating percentages of quitting and relapse.[16] Fifth, our analysis did not examine factors (other than age and gender) that affected quitting and relapse or the reasons for quitting and relapse. This is because many of these factors are time-varying variables. In order to
include these variables in the analysis, values of these variables would need to be treated as additional transitional states which would make our model too complicated to estimate.

**Conclusions:** This study estimated smoking patterns (quitting and relapse) and the benefit of quitting in a traditionally overlooked demographic subgroup.[3,31] These estimates are currently unavailable for the U.S. general population of older adults and would enable an understanding of the trajectory and impact of tobacco use. Such information also would help guide the investment of smoking cessation services as the population ages. Future data collection should include a respondent’s number of prior quit attempts and times advised to quit smoking, given that both will influence quit rates and, ultimately, guide resource allocation and risk messaging. [15,37] Additionally, further investigations should aim to develop a broader understanding of smoking cessation predictors to identify specific strategies that might work best for the elderly based on specific sociodemographic features or chronic conditions.
**Data availability statement:** This study is a secondary data analysis using the Limited Data Set (LDS) of the HOS from the U.S. Centers for Medicare & Medicaid Services (CMS). The dataset contains potentially identifying or sensitive patient information (e.g., participants’ zip code, date of birth, date of death, etc.). A signed Data Use Agreement (DUA) with CMS is required to obtain LDS data files ([https://www.cms.gov/Research-Statistics-Data-and-Systems/Files-for-Order/LimitedDataSets/HOS](https://www.cms.gov/Research-Statistics-Data-and-Systems/Files-for-Order/LimitedDataSets/HOS)). In order to request a LDS files, investigators must follow the instructions on this link: [https://www.cms.gov/Research-Statistics-Data-and-Systems/Files-for-Order/Data-Disclosures-Data-Agreements/EPPEpilot-LDSS](https://www.cms.gov/Research-Statistics-Data-and-Systems/Files-for-Order/Data-Disclosures-Data-Agreements/EPPEpilot-LDSS).

**Ethical approval statement:** The study was reviewed and approved by the Columbia University Medical Center institutional review board (IRB-AAAR4154).

**Contributors:** HJ was in charge of the conceptualization, methodology, software, validation, and data curation. Both authors (HJ and EIL) were involved in the writing, editing, and visualization; both authors read and approved the final manuscript.

**Competing interests:** The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Figure 1: Transition Models of Smoking Status.

Figure 2: Percent of Quitting in Remaining Lifetime, Successful Quitting, and Relapse by Age

Legend

Panel 1: Percent of Quitting
- Daily smokers
- Some days smokers

Panel 2: Percent of Successful Quitting
- Daily smokers
- Some days smokers

Panel 3: Percent of Relapse
Figure 1: Transition Models of Smoking Status.

66x71mm (1200 x 1200 DPI)
Figure 2: Percent of Quitting in Remaining Lifetime, Successful Quitting, and Relapse by Age

Legend
Panel 1: Percent of Quitting
Daily smokers
Some days smokers
Panel 2: Percent of Successful Quitting
Daily smokers
Some days smokers
Panel 3: Percent of Relapse

62x101mm (1200 x 1200 DPI)
Appendix: Estimation of Transition Probabilities

A1. Estimation for Model A: Individuals with missing smoking status at both baseline and follow-up surveys were excluded from all analyses. Individuals who did not participate the follow-up survey and individuals with missing smoking status at one of the two surveys were included in estimation of probability of death only and were excluded from the estimation of transition between different smoking statuses.

For Model A, all transition probabilities ($p_{t}^{ij}, i, j \leq 3$) from age $t$ to $t + 2$ ($t = 65, 67, \ldots$) between three smoking states ($s_1, s_2, s_3$) were obtained by estimating instantaneous transition rates at age $t$, $\mu_{t}^{ij} = \lim_{\Delta \to 0} \frac{Pr(s_{t+\Delta}=j|s_{t}=i)}{\Delta}$, from a log-linear model with age (as a cubic polynomial function) as a time-dependent predictor. Assuming a constant instantaneous transition rate in an age interval, we obtained transition probability as $p_{t}^{ij} = 1 - \exp(-2\mu_{t}^{ij})$.[16,22]

The probability of death ($p_{t}^{i4}$) for smoking state $s_i$ ($i = 1, 2, 3$) during age interval $t$ to $t + 2$ was estimated based on the probability of death for the total population and hazard ratio of death for each state relative to the reference group (“not smoking”) at different ages. Using data estimated from the 2012 U.S. life tables, let $p_t$ be probability of death, and $l_t^i$ be number of persons surviving to age $t$ in state $s_i$, and $l_t$ be number of persons surviving to age $t$. Using an estimation from a Cox proportional hazard model with age as a time-varying covariate from the HOS data, let $h_t^i$ ($i = 1, 2$) be the hazard ratio of death for state $s = (s_2, s_3)$ relative to the reference state ($s_1$) at age $t$. Assuming a constant risk of death during each age interval, we estimated $p_{t}^{i4}$ ($i = 1, 2, 3$) by solving the following nonlinear equations numerically:[16]

$$\sum_{i=1}^{3} l_t^i p_t^{i4} = l_t p_t$$

$$p_t^{i4k+1} = 1 - (1 - p_t^{14k+1})^{h_t^i}, \quad i = 1, 2.$$
A2. Estimation for Model B: Six transition probabilities \(p^{1,1}, p^{1,2}, p^{1,4}, p^{2,1}, p^{2,2}, \) and \(p^{2,4}\) are from Model A directly. To estimate remaining eight transition probabilities: \(p^{1,3A}, p^{2,3A}, p^{3A,1}, p^{3A,2}, p^{3A,3B}, p^{3B,3B}, p^{3A,4},\) and \(p^{3B,4},\) let \(w\) be the proportion in state \(s_{3A}\) among total non-smoking states (i.e., in \(s_{3A}\) or \(s_{3B}\)). We estimated proportions in state \(s_{3A}\) and state \(s_{3B}\) among the total population at age \(t\) from logistic models and obtained \(w\) from these two proportions as \(w = \frac{\Pr(s_{3A}=1)}{\Pr(s_{3B}=1)+\Pr(s_{3A}=1)}\). Let \(HR_{3A:3B}\) be the hazard ratio of death for state \(s_{3A}\) relative to state \(s_{3B}\), and \(HR_{3A:3B}\), at age \(t\) were estimated from a Cox proportional hazard model with age as a time-varying covariate from the HOS data.[16]

Given that \(p^{1,3}, p^{2,3}, p^{3A,2}, p^{3A,4}, w, \) and \(HR_{3A:3B}\) were known, we can obtain these eight unknowns by solving following eight equations:

1. \(p^{1,3A}(\text{Model } B) = p^{1,3} (\text{Model } A);\)
2. \(p^{2,3A}(\text{Model } B) = p^{2,3} (\text{Model } A);\)
3. \(wp^{3A,1}(\text{Model } B) = p^{3A,1} (\text{Model } A);\)
4. \(wp^{3A,2}(\text{Model } B) = p^{3A,2} (\text{Model } A);\)
5. \(p^{3B,3B} + p^{3B,4} = 1;\)
6. \(w p^{3A,3B} + (1-w)p^{3B,3B} (\text{Model } B) = p^{3A,3B} (\text{Model } A);\)
7. \(wp^{3A,4} + (1-w)p^{3B,4} (\text{Model } B) = p^{3A,4} (\text{Model } A);\)
8. \(p^{3A,4} = 1 - (1-p^{3B,4})HR_{3A:3B}.\)

Equations (1) and (2) are based on the number of (daily and occasional) smokers who become nonsmokers in Model B which equals that in Model A; (3) and (4) are based on recent nonsmokers who become smokers in Model B which is equal to the nonsmokers who become smokers in Model A; (5) is based on linear dependence, \(\sum_{j=1}^{k+1} p_t^{ij} = 1 \) for \(i = 3B;\) (6) is based on the number of nonsmokers (both recent and longtime) who become longtime nonsmokers in Model B being equal to the number of nonsmokers who remain nonsmokers in Model A; (7) is based on the number of deaths for nonsmokers (recent and longtime) in Model B being equal to the
number of deaths for nonsmokers in Model A; and (8) is based on the relationship between the probability of
death for recent nonsmokers and longtime nonsmokers.

Solutions for $p^{1,3A}, p^{2,3A}, p^{3A,1}$, and $p^{3A,2}$ can be obtained directly from equations (1)-(4), while
solutions for $p^{3A,3B}, p^{3B,3B}, p^{3A,4}$, and $p^{3B,4}$ are obtained by solving nonlinear equations (5)-(8) numerically.

**A3. Estimation for Model C:** Nine transition probabilities ($p^{1,1}, p^{1,2}, p^{1,3A}, p^{1,4}, p^{2,1}, p^{2,2}, p^{2,3A}, p^{2,4}$, and
$p^{3A,4}$) are from Model B directly. The remaining nine transition probabilities: $p^{3A,1}, p^{3A,2}, p^{3A,3B1}, p^{3B,11}$,
$p^{3B,12}, p^{3B,3B2}, p^{3B,14}, p^{3B,23B2},$ and $p^{3B,4}$, can be estimated using the similar method described in A2. Let

$$w_1 = \frac{Pr(s_{3A}=1)}{Pr(s_{3A}=1)+Pr(s_{3B}1=1)}$$

and

$$w_2 = \frac{Pr(s_{3B}=1)}{Pr(s_{3B}=1)+Pr(s_{3B}=1)}.$$  

Because $Pr(s_{3B}=1)$ and $Pr(s_{3A}=1)$ are available
from Model B (see Appendix A2) and $Pr(s_{3B}1=1) + Pr(s_{3B}2=1) = Pr(s_{3B}=1)$, we just need to estimate
$Pr(s_{3B}1=1)$ in order to obtain $w_1$ and $w_2$. Let $l^x_i$ be number of persons in state $s_i$ at age $x$. Based on Model C
definition, the number of persons in state $s_{3B1}$ at age $x$ equals the number of persons in state $s_{3A}$ at age $x - 2$
minus the number of persons who died between age $x - 2$ and $x$, i.e.,

$$l^x_{3B1} = l^x_{3A} - l^x_{3B}(1 - p_{x-2}^{3A,4} - p_{x-2}^{3A,1} - p_{x-2}^{3A,2}).$$

We can obtain $Pr(s_{3B}1=1)$ using this equation.

Given that $w_1$ and $w_2$ are known, we can obtain the remaining ten unknowns by solving the following
nine equations numerically:

1. \( p^{3B,11} = RR \times p^{3A,1} \)
2. \( p^{3B,12} = RR \times p^{3A,2} \)
3. \( p^{3B,1A} = p^{3B,2A} \text{ or } p^{3B,1A} = p^{3A,4} \)
4. \( w_1 p^{3A,1} + (1 - w_1) p^{3B,11} \text{ (Model C) } = p^{3A,1} \text{ (Model B) } \)
5. \( w_1 p^{3A,2} + (1 - w_1) p^{3B,12} \text{ (Model C) } = p^{3A,2} \text{ (Model B) } \)
6. \( p^{3A,3B1} \text{ (Model C) } = p^{3A,3B} \text{ (Model B) } \)
7. \( w_2 p^{3B,13B2} + (1 - w_2) p^{3B,23B2} \text{ (Model C) } = p^{3B,3B} \text{ (Model B) } \)
Equations (1) and (2) are Model C assumption 1. We used $RR = 0.05$ or $0.15$ for lower and upper bound, respectively; (3) is Model C assumption 2. We used $p^{3B1,4} = p^{3B2,4}$ or $p^{3B1,4} = p^{3A,4}$ for lower and upper bound, respectively; (4) and (5) are based on the number of nonsmokers (both $3A$ and $3B1$) who become (daily and occasional) smokers in Model C being equal to the number of recent nonsmokers ($3A$) who become smokers in Model B; (6) is based on the number of recent quitters ($3A$) who become longtime nonsmokers (2-4 years abstinence, $3B1$) in Model C being equal to the number of recent quitters becoming longtime nonsmokers ($3B$) in Model B; (7) is based on the number of total longtime smokers ($3B1$ and $3B2$) who remain longtime nonsmokers ($3B2$ only) in Model C being equal to the number of longtime smokers ($3B$) who remain longtime nonsmokers ($3B$) in Model B; (8) is based on the number of deaths for total longtime nonsmokers ($3B1$ and $3B2$) in Model C being equal to the number of deaths for longtime nonsmokers ($3B$) in Model B; and (9) is based on the linear dependence, $\sum_{j=1}^{k+1} p_t^{i,j} = 1$ for $i = 3B2$. 

\begin{align*}
(8) & \quad w_2 p^{3B1,4} + (1-w_2) p^{3B2,4} \ (Model \ C) = p^{3B4} (Model \ B) \\
(9) & \quad p^{3B2,3B2} + p^{3B2,4} = 1
\end{align*}
Supplementary Tables

Table S1: Sample Characteristics at Baseline and Follow-up

|                          | Baseline N and Percent | Follow-up N and Percent |
|--------------------------|------------------------|-------------------------|
| **Total sample**         | 164,597 100%           | 100,290 100%            |
| **Age, Mean (SD)**       |                        |                         |
| 65-74                    | 87,972 53.4%           | 47,929 47.8%            |
| 75-84                    | 55,676 33.8%           | 39,337 39.2%            |
| 85-94                    | 19,313 11.7%           | 12,308 12.3%            |
| 95+                      | 1,636 1.0%             | 716 0.7%                |
| **Gender**               |                        |                         |
| Female                   | 95,115 57.8%           | 58,519 58.4%            |
| **Race/ethnicity**       |                        |                         |
| White non-Hispanics      | 121,334 76.1%          | 77,694 78.2%            |
| Black non-Hispanics      | 13,031 8.2%            | 7,427 7.5%              |
| Hispanics                | 15,735 9.9%            | 8,803 8.9%              |
| Other                    | 9,404 5.9%             | 5,408 5.4%              |
| **Education at baseline**|                        |                         |
| < High school            | 34,844 22.0%           | 18,966 19.3%            |
| High school              | 55,775 35.3%           | 34,711 35.3%            |
| Some college             | 37,473 23.7%           | 23,399 23.8%            |
| College graduate         | 30,008 19.0%           | 21,169 21.5%            |
| **Family income at baseline** |                  |                         |
| < $20,000                | 48,991 37.7%           | 27,653 33.5%            |
| $20,000-50,000           | 43,118 33.2%           | 28,032 33.9%            |
| $50,000-80,000           | 27,749 21.4%           | 19,628 23.8%            |
| >=$80,000                | 9,962 7.7%             | 7,282 8.8%              |
| **Do you now smoke?**   |                        |                         |
| Every day                | 10,448 6.6%            | 4,883 5.2%              |
| Some days                | 5,004 3.1%             | 2,524 2.7%              |
| Not at all               | 143,512 90.3%          | 86,498 92.1%            |
| **Smoke by gender**      |                        |                         |
| Men                      |                        |                         |
| Smoke every day          | 5,118 7.6%             | 2,274 5.8%              |
| Smoke some days          | 2,270 3.4%             | 1,205 3.1%              |
| Not smoke at all         | 59,671 89.0%           | 35,636 91.1%            |
| Women                    |                        |                         |
| Smoke every day          | 5,330 5.8%             | 2,609 4.8%              |
| Smoke some days          | 2,734 3.0%             | 1,319 2.4%              |
| Not smoke at all         | 83,841 91.2%           | 50,862 92.8%            |
Table S2: Standard Error of Estimates in Figure 2

| Age (x) | Percent quitting every day | Percent quitting some day | Percent successful quitting every day | Percent successful quitting some day | Percent Relapse |
|---------|-----------------------------|---------------------------|--------------------------------------|-------------------------------------|-----------------|
| 65      | 1.5%                        | 1.5%                      | 1.5%                                 | 1.5%                                | 1.6%            |
| 67      | 1.5%                        | 1.5%                      | 1.4%                                 | 1.5%                                | 2.1%            |
| 69      | 1.6%                        | 1.7%                      | 1.4%                                 | 1.7%                                | 2.0%            |
| 71      | 1.6%                        | 1.9%                      | 1.3%                                 | 1.7%                                | 2.1%            |
| 73      | 1.7%                        | 2.0%                      | 1.3%                                 | 1.8%                                | 2.2%            |
| 75      | 1.8%                        | 2.2%                      | 1.3%                                 | 1.8%                                | 2.3%            |
| 77      | 1.8%                        | 2.3%                      | 1.2%                                 | 1.7%                                | 2.5%            |
| 79      | 1.9%                        | 2.4%                      | 1.2%                                 | 1.6%                                | 2.6%            |
| 81      | 2.0%                        | 2.5%                      | 1.2%                                 | 1.6%                                | 2.8%            |
| 83      | 2.1%                        | 2.6%                      | 1.3%                                 | 1.7%                                | 2.9%            |
| 85      | 2.2%                        | 2.7%                      | 1.4%                                 | 1.8%                                | 3.1%            |
| 87      | 2.3%                        | 3.0%                      | 1.5%                                 | 2.1%                                | 3.3%            |
| 89      | 2.4%                        | 3.3%                      | 1.7%                                 | 2.5%                                | 3.6%            |
| 91      | 2.5%                        | 3.8%                      | 1.9%                                 | 3.1%                                | 3.9%            |
| 93      | 2.6%                        | 4.6%                      | 2.1%                                 | 3.9%                                | 4.3%            |
| 95      | 2.8%                        | 5.8%                      | 2.3%                                 | 5.2%                                | 4.6%            |
Table S3: Probabilities of Quitting, Successful Quitting, and Relapse at Ages 65-95 Years, by Sex

| Age (x) | Probability of quitting daily smokers | Probability of quitting some days smokers | Probability of successful quitting daily smokers | Probability of successful quitting some days smokers | Probability of relapse |
|---------|--------------------------------------|------------------------------------------|-----------------------------------------------|------------------------------------------------|-----------------------|
| 65      | 59.4%                                | 68.4%                                    | 26.4%                                         | 32.1%                                           | 57.9%                 |
| 67      | 56.6%                                | 66.6%                                    | 23.9%                                         | 30.1%                                           | 50.0%                 |
| 69      | 53.4%                                | 64.7%                                    | 20.5%                                         | 26.8%                                           | 45.8%                 |
| 71      | 50.1%                                | 62.7%                                    | 16.8%                                         | 22.9%                                           | 44.4%                 |
| 73      | 46.7%                                | 60.7%                                    | 12.9%                                         | 18.5%                                           | 44.8%                 |
| 75      | 43.5%                                | 58.7%                                    | 9.4%                                          | 14.0%                                           | 46.4%                 |
| 77      | 40.5%                                | 56.4%                                    | 6.5%                                          | 10.0%                                           | 49.3%                 |
| 79      | 37.6%                                | 53.9%                                    | 4.5%                                          | 6.9%                                            | 52.7%                 |
| 81      | 35.0%                                | 51.3%                                    | 3.5%                                          | 5.1%                                            | 56.8%                 |
| 83      | 32.9%                                | 48.3%                                    | 3.4%                                          | 4.7%                                            | 60.3%                 |
| 85      | 31.5%                                | 44.5%                                    | 3.8%                                          | 5.1%                                            | 62.3%                 |
| 87      | 30.3%                                | 40.9%                                    | 4.2%                                          | 5.6%                                            | 63.0%                 |
| 89      | 29.7%                                | 37.0%                                    | 4.3%                                          | 5.2%                                            | 61.2%                 |
| 91      | 30.1%                                | 32.7%                                    | 4.9%                                          | 5.1%                                            | 56.3%                 |
| 93      | 31.0%                                | 28.2%                                    | 5.8%                                          | 5.1%                                            | 48.8%                 |
| 95      | 32.5%                                | 24.3%                                    | 7.0%                                          | 5.1%                                            | 38.7%                 |

| Age (x) | Probability of quitting daily smokers | Probability of quitting some days smokers | Probability of successful quitting daily smokers | Probability of successful quitting some days smokers | Probability of relapse |
|---------|--------------------------------------|------------------------------------------|-----------------------------------------------|------------------------------------------------|-----------------------|
| 65      | 63.1%                                | 69.1%                                    | 36.0%                                         | 40.9%                                           | 47.7%                 |
| 67      | 59.0%                                | 67.3%                                    | 32.0%                                         | 38.4%                                           | 42.0%                 |
| 69      | 55.2%                                | 64.8%                                    | 27.9%                                         | 34.9%                                           | 39.1%                 |
| 71      | 51.5%                                | 61.7%                                    | 24.0%                                         | 30.7%                                           | 39.0%                 |
| 73      | 47.7%                                | 58.1%                                    | 20.2%                                         | 26.2%                                           | 40.3%                 |
| 75      | 43.7%                                | 54.2%                                    | 16.7%                                         | 21.8%                                           | 43.0%                 |
| 77      | 39.4%                                | 50.3%                                    | 13.4%                                         | 17.9%                                           | 46.5%                 |
| 79      | 34.7%                                | 46.5%                                    | 10.7%                                         | 14.7%                                           | 50.3%                 |
| 81      | 29.7%                                | 43.0%                                    | 8.6%                                          | 12.3%                                           | 54.0%                 |
| 83      | 24.0%                                | 40.3%                                    | 6.9%                                          | 11.2%                                           | 56.4%                 |
| 85      | 18.2%                                | 38.6%                                    | 5.6%                                          | 11.1%                                           | 56.6%                 |
| 87      | 12.6%                                | 38.1%                                    | 4.3%                                          | 12.1%                                           | 53.6%                 |
| 89      | 7.8%                                 | 38.9%                                    | 2.9%                                          | 14.3%                                           | 47.7%                 |
| 91      | 4.3%                                 | 41.3%                                    | 1.8%                                          | 17.2%                                           | 38.8%                 |
| 93      | 2.0%                                 | 45.8%                                    | 0.9%                                          | 20.6%                                           | 28.8%                 |
| 95      | 0.8%                                 | 52.6%                                    | 0.3%                                          | 23.8%                                           | 20.0%                 |
Table S4: Standard Error of Estimates in Figure 2

| Age (x) | Smokers daily | Smokers some days | All smokers | None smokers Recent¹ | None smokers Long time² | All non-smokers | Quitting vs. not quitting³ | Non-smokers vs. smokers⁴ |
|---------|---------------|-------------------|-------------|----------------------|-------------------------|------------------|---------------------------|---------------------------|
| 65      | 0.29          | 0.29              | 0.29        | 0.30                 | 0.27                    | 0.52             | 0.42                      | 0.59                      |
| 67      | 0.27          | 0.27              | 0.27        | 0.28                 | 0.26                    | 0.51             | 0.39                      | 0.57                      |
| 69      | 0.26          | 0.26              | 0.26        | 0.27                 | 0.25                    | 0.49             | 0.37                      | 0.56                      |
| 71      | 0.24          | 0.24              | 0.24        | 0.25                 | 0.24                    | 0.48             | 0.35                      | 0.54                      |
| 73      | 0.22          | 0.22              | 0.22        | 0.23                 | 0.22                    | 0.47             | 0.32                      | 0.52                      |
| 75      | 0.21          | 0.21              | 0.21        | 0.22                 | 0.21                    | 0.46             | 0.30                      | 0.50                      |
| 77      | 0.19          | 0.19              | 0.19        | 0.20                 | 0.20                    | 0.44             | 0.28                      | 0.48                      |
| 79      | 0.18          | 0.18              | 0.18        | 0.19                 | 0.18                    | 0.43             | 0.26                      | 0.46                      |
| 81      | 0.17          | 0.17              | 0.17        | 0.17                 | 0.17                    | 0.41             | 0.24                      | 0.44                      |
| 83      | 0.15          | 0.15              | 0.15        | 0.16                 | 0.15                    | 0.39             | 0.22                      | 0.42                      |
| 85      | 0.14          | 0.14              | 0.14        | 0.14                 | 0.14                    | 0.37             | 0.20                      | 0.40                      |
| 87      | 0.13          | 0.13              | 0.13        | 0.13                 | 0.13                    | 0.36             | 0.19                      | 0.38                      |
| 89      | 0.12          | 0.13              | 0.12        | 0.12                 | 0.11                    | 0.34             | 0.17                      | 0.36                      |
| 91      | 0.12          | 0.12              | 0.12        | 0.11                 | 0.10                    | 0.32             | 0.16                      | 0.34                      |
| 93      | 0.11          | 0.11              | 0.11        | 0.10                 | 0.09                    | 0.30             | 0.15                      | 0.32                      |
| 95      | 0.10          | 0.11              | 0.11        | 0.10                 | 0.08                    | 0.29             | 0.14                      | 0.30                      |

¹: quit less than 2 years  
²: never smoke or quit ≥ 2 years  
³: difference between recent non-smokers and smokers  
⁴: difference between all non-smokers and all smokers
Table S5: Life Expectancy by Initial Smoking Status at Ages 65-95 Years, by Sex

| Age (x) | Current smokers | Not smoking at all | Quitting vs. not quitting | Non-smokers vs. smokers |
|---------|-----------------|--------------------|---------------------------|-------------------------|
|         | Daily smokers   | Some days smokers  | All smokers               |                         |                        |
|         | Long time<sup>2</sup> | All non-smokers |                          |                         |                        |
|         |                 |                    |                           |                         |                        |
|         | Recent<sup>1</sup> |                    |                           |                         |                        |

**Men**

| Age (x) | Current smokers | Not smoking at all | Quitting vs. not quitting | Non-smokers vs. smokers |
|---------|-----------------|--------------------|---------------------------|-------------------------|
|         | Daily smokers   | Some days smokers  | All smokers               |                         |                        |
|         | Long time<sup>2</sup> | All non-smokers |                          |                         |                        |
|         | Recent<sup>1</sup> |                    |                           |                         |                        |

| 65      | 14.8            | 15.2              | 14.9                      | 15.1                    | 18.7                    | 18.6                    | 0.2*                    | 3.7*                    |
| 67      | 13.4            | 14.0              | 13.6                      | 14.5                    | 17.2                    | 17.1                    | 0.9*                    | 3.5*                    |
| 69      | 12.0            | 12.8              | 12.2                      | 13.4                    | 15.7                    | 15.6                    | 1.2*                    | 3.3*                    |
| 71      | 10.8            | 11.6              | 11.0                      | 12.2                    | 14.2                    | 14.1                    | 1.2*                    | 3.1*                    |
| 73      | 9.6             | 10.6              | 9.9                       | 10.9                    | 12.8                    | 12.7                    | 1.0*                    | 2.8*                    |
| 75      | 8.7             | 9.6               | 9.0                       | 9.6                     | 11.4                    | 11.4                    | 0.7*                    | 2.4*                    |
| 77      | 7.8             | 8.7               | 8.1                       | 8.4                     | 10.2                    | 10.1                    | 0.3*                    | 2.1*                    |
| 79      | 7.0             | 7.9               | 7.3                       | 7.2                     | 9.0                     | 9.0                     | -0.1                    | 1.6*                    |
| 81      | 6.4             | 7.1               | 6.6                       | 6.2                     | 7.9                     | 7.9                     | -0.4                    | 1.2*                    |
| 83      | 5.8             | 6.4               | 6.0                       | 5.5                     | 6.9                     | 6.9                     | -0.5                    | 0.8*                    |
| 85      | 5.3             | 5.7               | 5.4                       | 4.9                     | 6.0                     | 5.9                     | -0.5                    | 0.5*                    |
| 87      | 4.7             | 5.0               | 4.8                       | 4.6                     | 5.1                     | 5.1                     | -0.2                    | 0.3                    |
| 89      | 4.2             | 4.2               | 4.2                       | 4.2                     | 4.4                     | 4.4                     | 0.0                     | 0.2                    |
| 91      | 3.8             | 3.4               | 3.6                       | 3.6                     | 3.8                     | 3.8                     | -0.1                    | 0.2                    |
| 93      | 3.4             | 2.8               | 3.1                       | 3.0                     | 3.3                     | 3.3                     | -0.1                    | 0.2                    |
| 95      | 3.0             | 2.2               | 2.7                       | 2.6                     | 2.9                     | 2.9                     | -0.1                    | 0.2                    |

**Women**

| Age (x) | Current smokers | Not smoking at all | Quitting vs. not quitting | Non-smokers vs. smokers |
|---------|-----------------|--------------------|---------------------------|-------------------------|
|         | Daily smokers   | Some days smokers  | All smokers               |                         |                        |
|         | Long time<sup>2</sup> | All non-smokers |                          |                         |                        |
|         | Recent<sup>1</sup> |                    |                           |                         |                        |

| 65      | 17.2            | 17.4              | 17.2                      | 18.7                    | 21.0                    | 21.0                    | 1.5*                    | 3.7*                    |
| 67      | 15.6            | 15.9              | 15.7                      | 17.3                    | 19.4                    | 19.3                    | 1.7*                    | 3.7*                    |
| 69      | 14.0            | 14.4              | 14.2                      | 15.8                    | 17.8                    | 17.7                    | 1.7*                    | 3.5*                    |
| 71      | 12.6            | 13.0              | 12.7                      | 14.3                    | 16.2                    | 16.1                    | 1.6*                    | 3.4*                    |
| 73      | 11.3            | 11.6              | 11.4                      | 12.8                    | 14.7                    | 14.6                    | 1.4*                    | 3.2*                    |
| 75      | 10.1            | 10.4              | 10.2                      | 11.4                    | 13.2                    | 13.2                    | 1.2*                    | 3.0*                    |
| 77      | 9.0             | 9.2               | 9.1                       | 10.0                    | 11.8                    | 11.8                    | 1.0*                    | 2.7*                    |
| 79      | 8.0             | 8.1               | 8.1                       | 8.8                     | 10.5                    | 10.4                    | 0.7*                    | 2.4*                    |
| 81      | 7.2             | 7.2               | 7.2                       | 7.7                     | 9.2                     | 9.2                     | 0.5*                    | 2.0*                    |
| 83      | 6.4             | 6.4               | 6.4                       | 6.8                     | 8.1                     | 8.1                     | 0.3*                    | 1.7*                    |
| 85      | 5.8             | 5.7               | 5.7                       | 6.0                     | 7.0                     | 7.0                     | 0.2*                    | 1.3*                    |
| 87      | 5.2             | 5.1               | 5.2                       | 5.3                     | 6.1                     | 6.1                     | 0.2*                    | 0.9*                    |
| 89      | 4.7             | 4.6               | 4.7                       | 4.8                     | 5.2                     | 5.2                     | 0.1                     | 0.5*                    |
| 91      | 4.3             | 4.2               | 4.3                       | 4.3                     | 4.5                     | 4.5                     | 0.0                     | 0.2*                    |
| 93      | 3.9             | 3.9               | 3.9                       | 3.9                     | 3.9                     | 3.9                     | 0.0                     | -0.1                    |
| 95      | 3.6             | 3.6               | 3.6                       | 3.4                     | 3.3                     | 3.3                     | -0.2                    | -0.3                    |

<sup>1</sup>: quit less than 2 years.  <sup>2</sup>: never smoke or quit ≥ 2 years.  <sup>3</sup>: difference between recent non-smokers and smokers.  
<sup>4</sup>: difference between all non-smokers and all smokers.  
<sup>*</sup>: p < 0.05 for testing for difference between 2 groups.
## STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of cohort studies

| Section/Topic               | Item # | Recommendation                                                                 | Reported on page # |
|-----------------------------|--------|---------------------------------------------------------------------------------|--------------------|
| **Title and abstract**      | 1      | (a) Indicate the study’s design with a commonly used term in the title or the abstract | 2                  |
|                             |        | (b) Provide in the abstract an informative and balanced summary of what was done and what was found | 2                  |
| **Introduction**            | 2      | Explain the scientific background and rationale for the investigation being reported | 4-5                |
| **Objectives**              | 3      | State specific objectives, including any prespecified hypotheses                  | 5                  |
| **Methods**                 | 4      | Present key elements of study design early in the paper                           | 5-6                |
| Study design                | 5      | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection | 6                  |
| Setting                     | 6      | (a) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up | 6                  |
|                             |        | (b) For matched studies, give matching criteria and number of exposed and unexposed | n/a                |
| Participants                | 7      | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable | 6-7                |
| Variables                   | 8*     | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group | 6-7                |
| Data sources/measurement    | 9      | Describe any efforts to address potential sources of bias                          | 9-10               |
| Bias                        | 10     | Explain how the study size was arrived at                                         | n/a                |
| Study size                  | 11     | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why | 6-7                |
| Quantitative variables      | 12     | (a) Describe all statistical methods, including those used to control for confounding | 7-10, 20-23        |
| Statistical methods         |        | (b) Describe any methods used to examine subgroups and interactions                | n/a                |
|                             |        | (c) Explain how missing data were addressed                                        | 6,25               |
|                             |        | (d) If applicable, explain how loss to follow-up was addressed                     | 6,25               |
|                             |        | (e) Describe any sensitivity analyses                                              | 9-10               |

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Participants 13*

(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed

(b) Give reasons for non-participation at each stage

(c) Consider use of a flow diagram

Descriptive data 14*

(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders

(b) Indicate number of participants with missing data for each variable of interest

(c) Summarise follow-up time (eg, average and total amount)

Outcome data 15*

Report numbers of outcome events or summary measures over time

Main results 16

(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included

(b) Report category boundaries when continuous variables were categorized

(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period

Other analyses 17

Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses

Discussion

Key results 18

Summarise key results with reference to study objectives

Limitations

Interpretation 20

Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence

Generalisability 21

Discuss the generalisability (external validity) of the study results

Other information

Funding 22

Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.