Original investigation

The Relations Between False Positive and Negative Screens and Smoking Cessation and Relapse in the National Lung Screening Trial: Implications for Public Health

Melissa A. Clark PhD[1,2], Jeremy J. Gorelick PhD[3], JoRean D. Sicks MS[3], Elyse R. Park PhD, MPH[4,5], Amanda L. Graham PhD[6,7], David B. Abrams PhD[6,7,8], Ilana F. Gareen PhD[1,3]

[1]Department of Epidemiology, Brown University School of Public Health, Providence, RI; [2]Center for Population Health and Clinical Epidemiology, Brown University, Providence, RI; [3]Center for Statistical Sciences, Brown University School of Public Health, Providence, RI; [4]Department of Psychiatry, Harvard Medical School, Boston, MA; [5]Cancer Center and Mongan Institute for Health Policy, Massachusetts General Hospital, Boston, MA; [6]Schroeder Institute for Tobacco Research and Policy Studies, American Legacy Foundation, Washington, DC; [7]Department of Oncology, Georgetown University Medical Center/Cancer Control Program, Lombardi Comprehensive Cancer Center, Washington, DC; [8]Department of Health, Behavior and Society, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD

Corresponding Author: Melissa A. Clark, PhD, Department of Epidemiology, Brown University School of Public Health, Box G-121-6, Providence, RI 02912, USA. Telephone: 401-863-3170; Fax: 401-863-7912; E-mail: Melissa_Clark@brown.edu

Abstract

Introduction: Lung screening is an opportunity for smoking cessation and relapse prevention, but smoking behaviors may differ across screening results. Changes in smoking were evaluated among 18 840 current and former smokers aged 55–74 scheduled to receive three annual lung screenings.

Methods: Participants were randomized to low-dose computed tomography or single-view chest radiography in the American College of Radiology/National Lung Screening Trial. Outcome measures included point and sustained (6-month) abstinence and motivation to quit among smokers; and relapse among smokers who quit during follow-up, recent quitters (quit < 6 months), and long-term former smokers (quit ≥ 6 months).

Results: During five years of follow-up, annual point prevalence quit rates ranged from 11.6%–13.4%; 48% of current smokers reported a quit attempt and 7% of long-term former smokers relapsed. Any false positive screening result was associated with subsequent increased point (multivariable hazard ratio HR = 1.23, 95% CI = 1.13, 1.35) and sustained (HR = 1.28, 95% CI = 1.15, 1.43) abstinence among smokers. Recent quitters with ≥1 false positive screen were less likely to relapse (HR = 0.72, 95% CI = 0.54, 0.96). Screening result was not associated with relapse among long-term former smokers or among baseline smokers who quit during follow-up.

Conclusions: A false positive screen was associated with increased smoking cessation and less relapse among recent quitters. Consistently negative screens were not associated with greater relapse among long-term former smokers. Given the Affordable Care Act requires most health plans to cover smoking cessation and lung screening, the impact and cost-effectiveness of lung screening could be further enhanced with the addition of smoking cessation interventions.

Introduction

Lung cancer is the leading cause of cancer death in the United States for men and women with most cases diagnosed at later stages and 5-year survival rates of only 16%.[1] In 2011, the National Lung Screening Trial (NLST) reported a lung cancer mortality reduction of 20% for high-risk current and former smokers screened with low-dose computed tomography (LDCT) as opposed to chest x-ray (CXR).[2] Seven organizations, including the US Preventive Task Force, have since issued recommendations for high risk individuals to undergo annual lung cancer screening.[3–9] It is estimated that 8 million people in the United States meet high risk criteria, and lung screening could prevent 4000 deaths annually.[4] Simulation models indicate that the cost effectiveness of lung screening programs will be influenced by the smoking cessation rates among participants,[10] and all recommendations for screening have specified that screening programs incorporate a smoking cessation component.[3–9]

The relation between lung screening and smoking behaviors may differ based on smoking status at the time of the exam and the screening result. There is the potential for an iatrogenic effect of reassurance from negative screens,[4] which may reduce motivation to quit or lead to resumption of smoking. Since the vast majority of screens will be negative (>75% for LDCT and >90% for CXR),[2] their iatrogenic effect on smoking behavior may undermine the net benefits of screening and/or may not be offset by minimal smoking cessation counseling. On the other hand, a positive screen may increase motivation to quit or to remain abstinent. These potentially contrasting relations are particularly important for older adults targeted for lung screening, who have lengthy smoking histories,[11] are less likely to try to quit, but more likely to succeed when doing so.[12]

Beneficial changes in smoking behaviors have been documented for current and former smokers who received a positive versus negative lung screening result in studies with follow-up of 3 years or less.[13–16] Four randomized controlled trials of lung cancer screening have also reported smoking outcomes. All four trials found no differences in smoking cessation or relapse when comparing LDCT to no screening[17,18] or CXR to usual care.[19,20] However, there were inconsistent findings for the relation between screening result and smoking behaviors. The Danish Lung Cancer Screening trial reported higher rates of smoking cessation and relapse prevention among participants with a positive versus negative screen,[17] while screening result was not associated with changes in smoking behaviors in the Dutch–Belgium trial[21] or the Prostate, Lung, Colorectal, and Ovarian Cancer Screening trial.[19] Increasing motivation to quit is an important intermediary step in the cessation process. To date, only Taylor and colleagues[15] have included motivation to quit as an outcome when assessing the relation between screening status and smoking outcomes.

In a recent analysis, Tammemägi and colleagues[22] reported on results from smokers enrolled in the Lung Screening Study component of the NLST. They found that among baseline smokers, smoking cessation (ie, point abstinence) was associated with an abnormal screen result. The current study using data from the American College of Radiology Imaging Network (ACRIN) component of the NLST built on these findings by (1) assessing cessation outcomes beyond point abstinence to include sustained (6-month) abstinence as well as motivation to quit among baseline smokers and (2) examining relapse during the study among recently quit, long-term former smokers, and baseline smokers who quit. Specifically, among all ACRIN/NLST former and current smokers, we examined: (1) five-year follow-up rates of quitting and relapse; (2) the relation between screening result and quitting and relapse behaviors, and (3) the relation between screening and current smokers' motivation to quit.

Materials and Methods

Study Population

The NLST was a multi-institutional trial, described in detail elsewhere[23,24] and included the Lung Screening Study and ACRIN components. The effort was funded by the National Cancer Institute (NCI) Cancer Imaging Program, Division of Cancer Treatment and Diagnosis and the Division of Cancer Prevention. ACRIN was responsible for 18 840 of the 53 452 participants at 23 sites. The present study includes participants from the ACRIN sites, which collected extensive smoking measures.

Eligible participants were 55 to 74 years of age at the time of randomization with no lung cancer diagnosis during the course of the study, had a history of cigarette smoking of at least 30 pack-years, and, if a former smoker, had quit within the previous 15 years. Participants were randomly assigned to receive three screenings with LDCT or CXR, and current smokers were offered written information about smoking cessation. Participants were excluded from our analyses if they received a lung cancer diagnosis during the trial because a malignant diagnosis has been associated with high rates of smoking cessation and low rates of relapse.[25–27]

Data Collection

Participants were enrolled between August 2002 and April 2004. They completed a questionnaire on smoking history before randomization and prior to the first screening examination, and were asked to complete questionnaires about current smoking every 6 months through 2008. In 2009, the questionnaire was shortened and did not collect sufficient information to determine 6-month abstinence. Therefore, participants in the study at that date were censored 5.5 years from study enrollment or at December 31, 2008, whichever was first. All forms are located at www.acrin.org/Default. aspx?tabid=282. The study was approved by each institution's Institutional Review Board.

At baseline, participants who answered yes to, "Do you smoke cigarettes now?" were classified as current smokers. Participants who reported having their last cigarette at least 6 months before randomization were classified as long-term former smokers. Those who quit within 6 months of randomization were classified as recent quitters.

Outcomes

At each follow-up, participants were asked, "In the past six (6) months, have you smoked any cigarettes?" and if yes, "Do you NOW smoke cigarettes (one or more cigarettes per week)?" Among baseline smokers, abstinence at follow-up was based on self-reported smoking status on the day of questionnaire administration.

Point prevalence abstinence was defined as the first report by a participant of not currently smoking, and sustained abstinence was defined as no cigarettes smoked in the past 6 months. Among baseline former smokers, relapse was defined as a report of smoking (current or in the past 6 months) at any follow-up. To determine when smoking status changed, date of follow-up form submission was used as the date of abstinence or relapse. Time to quit for current smokers and time to relapse for former smokers were calculated as the length of time from enrollment until the first self-reported abstinence or relapse. Participants who died during the study or were

lost to follow-up were censored at their last smoking assessment. Participants were censored at the end of the study if they did not report a change in smoking status during the study period.

Motivation to quit (10-point scale from "I enjoy smoking so much I will never consider quitting" to "I have quit and I am 100% confident that I will never smoke again")[28] was assessed at baseline and at each follow-up.

Screening Result

We considered screening result as a time-dependent covariate. This variable took the value of the result at the first screening (T0) (false positive/negative) until the next screening, at which time the value of the result from the T1 screening (false positive/negative) was assumed. Similarly, the variable retained the value of the T1 screening until the final screening (T2). After the T2 screening, the variable retained the value of the T2 screening until the participant was lost to follow-up, died, or was censored at the end of the trial. Because all individuals diagnosed with lung cancer were excluded from the analyses, all positive screens were false positives. In total, 97% of the false positives had at least one year of follow-up.

Covariates

Demographics included age, gender, race, education, and marital status. Smoking history included age of smoking onset, age of stopping smoking (former smokers only), and cigarettes smoked per day when smoking the most. Nicotine addiction was assessed using the Fagerström Test for Nicotine Dependence.[29] Health history items included personal history of any cancer, personal history of any one of 15 smoking-related diseases, and family history of lung cancer.

Statistical Methods

Differences in baseline characteristics between current smokers, recent quitters, and long-term former smokers were analyzed using Pearson's chi-square tests for nominal or categorical variables and analysis of variance for continuous variables. Time-dependent Cox proportional hazards models were used to evaluate the effect of screening result on the time until a current smoker quit or until a former smoker relapsed, controlling for study arm, smoking history, health history, age, gender, race, education, and marital status. To supplement analyses about the relation between a false positive screen and smoking behaviors, we also calculated crude event rates for the year following the screening exam, stratified by screening outcomes. That is, we calculated the ratio of the number of people who had the event during the year following the screen to the number of people at risk of the event at the screen. Finally, a linear regression model was computed to evaluate the association between screening result and change from baseline to next screen in motivation to quit among current smokers with no quit attempts during the study period, controlling for baseline motivation to quit.

Results

Of 18 840 participants enrolled in ACRIN, we excluded 774 (4.1%) diagnosed with lung cancer during the trial, 1090 (5.8%) who did not complete follow-up forms annually and were missing information about smoking, and 12 (<0.1%) who reported a change in smoking status before screening (Figure 1). Of the 16 964 remaining participants, 8358 (49.3%) were current smokers at the time of randomization, 7820 (46.1%) were long-term former smokers, and 786 (4.6%) were recent quitters. Study participants had a total of

82 031 person years of follow-up (median = 5.0 years; range = 0.0–5.5 years) and their characteristics are shown in Table 1.

Cessation Among Baseline Smokers

Among current smokers at baseline (8358/16 964; 49.3%), the probability of at least one quit attempt (eg, point abstinence) by the end of the 5-year follow-up was 48.0% (95% confidence interval [CI] = 46.8, 49.2). At the end of 5 years of follow-up, the probability of smokers reporting a 6-month period of sustained abstinence was 33.8% (95% CI = 32.7, 34.9); annual rates are shown in Table 2.

Effect of Screening Result on Cessation Among Baseline Smokers

A false positive screening result was associated with an increased likelihood of both point (multivariable hazard ratio [HR] = 1.23, 95% CI = 1.13, 1.35; Figure 2a) and 6-month sustained (HR=1.28, 95% CI = 1.15, 1.43; Figure 2b) abstinence. The proportion of smokers who quit in the year after their first false positive screen was 15.9% (*n* = 1869) compared to 12.7% (*n* = 723) of smokers who quit in the year after a second false positive screen (χ^2 = 4.2, *P* = .04). Individuals with at least two false positive screens were not more likely than those with zero or one false positive screen to make a cessation attempt (for additional details regarding crude abstinence rates in the year following a screening exam by screening results, please see Supplementary Figure A1, a–f). There were no differences by study arm (LDCT vs. CXR) for point (HR =1.07, 95% CI = 1.00, 1.15) or sustained (HR =1.05, 95% CI = 0.98, 1.14) abstinence after accounting for screening result and other covariates.

Motivation to Quit Among Current Smokers

Among current smokers with no quit attempts during the study period (4413/16 964; 26.0%), a false positive baseline screen (β = 0.17, *SE* = 0.06, *t* = 2.87, *P* = .004) and randomization to LDCT versus CXR (β = 0.13, *SE* = 0.04, *t* = 3.11, *P* = .002) were associated with an increase in motivation to quit, controlling for baseline motivation and other covariates.

Relapse Among Former Smokers

Among recent quitters at baseline (786/16 964; 4.6%), the proportion who relapsed by the end of the 5-year follow-up was 65.5% (95% CI = 62.1, 68.9), with most relapse occurring in the first 2 years. Annual rates of relapse are shown in Table 2. The proportion of long-term former smokers who relapsed by the end of the 5-year follow-up was 7.3% (95% CI = 6.7, 7.9). Among baseline smokers who quit for at least 6 months during follow-up, 41.0% (95% CI = 38.5, 43.6) relapsed by the end of the 5-year follow-up.

Effect of Screening Result on Relapse Among Former Smokers

Recent quitters with any false positive screen were less likely to relapse than those with a negative screen (HR = 0.72, 95% CI = 0.54, 0.96; Figure 2c). The proportion of recent quitters who relapsed after a first false positive screen was 40.8% (*n* = 120) compared to 10.8% (*n* = 37) who relapsed after a second false positive screen (χ^2 = 11.4, *P* = .001). The number of false positive screens was not associated with relapse among recent quitters (For additional details regarding crude relapse rates among recent quitters in
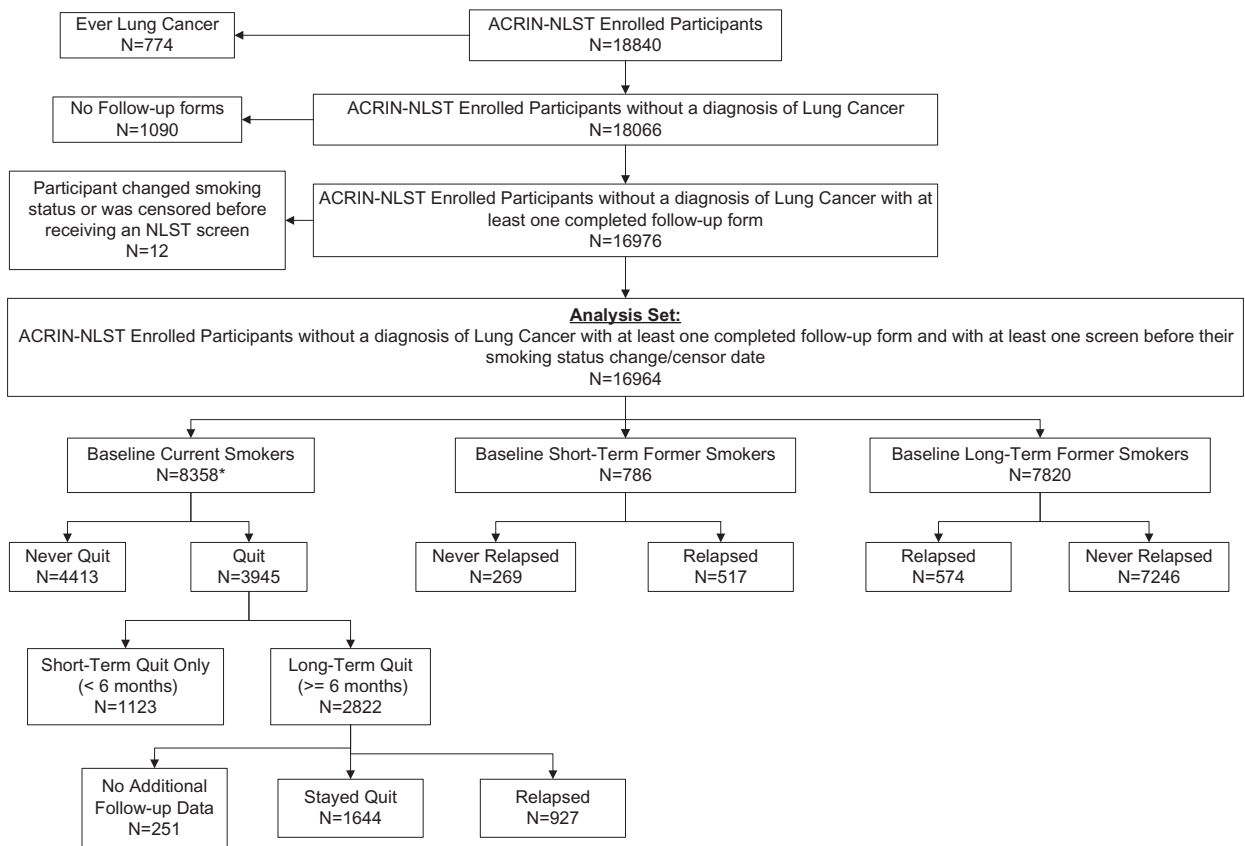
*71 baseline current smoker reported a short-term quit on or before the date they received their first NLST screen and therefore were not eligible to be included in the Short-Term Quit Analyses. These participants did report a long-term quit after their first screen date and therefore contribute to the Long-Term Quit analyses and are included in the analysis set as a baseline current smoker.

Figure 1. Flow diagram of participants in the National Lung Screening Trial (NLST-ACRIN)

the year following a screening exam by screening results, please see Supplementary Figure A1, g–i).

Among long-term former smokers (7820/16 964; 46.0%), any false positive screen was not associated with relapse (HR = 1.11, 95% CI = 0.87, 1.43; see also Figure 2d). The number of false positive screens also was not associated with relapse among long-term former smokers (For additional details regarding crude abstinence rates in the year following a screening exam by screening results, please see Supplementary Figure A1, j–l).

Among baseline smokers who quit during the 5 years of follow-up (3945/16 964; 23.2%), screening result was not associated with relapse (HR = 1.00, 95% CI = 0.82, 1.21; data not shown). Study arm was also not associated with relapse among any type of former smoker after accounting for other variables in the models.

For the full multivariable proportional hazards models of the likelihood of each smoking outcome, please see Supplementary Table A1.

Comment

Our findings demonstrated that lung screening was associated with increased smoking cessation and decreased relapse with no apparent iatrogenic effect of negative screen results. Although referrals to smoking cessation were offered, the NLST included no formal cessation component, such as those recommended by the updated

Public Health Service clinical guidelines for treating tobacco use and dependence.[30,31] However, almost half (48%) of baseline smokers reported at least one quit attempt with annual quit attempt rates of 11%–13% during the 5 years of follow-up. This is consistent with the smoking cessation results presented from the Lung Screening Study component of the NLST. Our findings also indicate that one-third (34%) of participants reported at least six months with no smoking (sustained abstinence) with annual rates of 4%–10%. Although direct comparisons cannot be made because of differences in definitions of abstinence, general population surveys of comparably-aged individuals have found annual sustained abstinence rates of about 5%.[12] Therefore, our findings are particularly noteworthy because they are from a large study of high risk smokers (eg, history of cigarette smoking of at least 30 pack-years) enrolled in a lung screening trial. Further, the findings contribute to the limited literature about the relation between lung screening and longer term smoking behaviors beyond 3 years of follow-up.[19,22,32]

Adding evidence-based smoking cessation treatments (eg, brief cessation advice by health-care providers; individual, group, and telephone counseling; and cessation medications) to lung screening could yield annual cessation rates as high as 20%–30%.[30,31] This could potentially save even more lives than screening alone by combining the detection of early and premalignant lesions for which there are available therapies with the delivery of efficacious smoking cessation treatments during a time when individuals may be

Table 1. Description of National Lung Screening Trial Participants

Characteristic	Smoking status at baseline			
	Smokers (*n* = 8358)	Recently quit former smokers (*n* = 786)	Long-term former smokers (*n* = 7820)	χ^2 or *F (P)*
Mean age in years (*SD*)	60.9 (4.9)	60.7 (4.6)	62.2 (5.1)	*F* = 149.6 (<.001)
Male gender (%)	54.1 (53.0, 55.2)	56.0 (52.4, 59.5)	55.9 (54.8, 57.1)	χ^2 = 5.8 (.056)
White race (%)	90.4 (89.8, 91.1)	93.1 (91.1, 94.8)	95.4 (94.9, 95.8)	χ^2 = 148.4 (<.001)
Education (%)				
College degree or more	31.2 (30.2, 32.2)	34.5 (31.2, 37.9)	36.9 (35.8, 37.9)	χ^2 = 81.8 (<.001)
Some college	34.4 (33.4, 35.4)	36.0 (32.6, 39.5)	34.1 (33.0, 35.1)	
High school or less	31.8 (30.8, 32.8)	26.2 (23.2, 29.4)	26.5 (25.6, 27.5)	
Other[a]	2.6 (2.3, 2.9)	3.3 (2.2, 4.8)	2.5 (2.2, 2.9)	
Marital status (%)				
Married or living as married	59.1 (58.0, 60.2)	61.6 (58.1, 65.0)	69.0 (68.0, 70.1)	χ^2 = 201.8 (<.001)
Divorced/separated	26.2 (25.3, 27.2)	25.8 (22.8, 29.0)	18.2 (17.4, 19.1)	
Widowed	8.3 (7.7, 8.9)	5.9 (4.3, 7.7)	7.4 (6.8, 8.0)	
Never married	6.1 (5.6, 6.6)	6.0 (4.4, 7.9)	5.0 (4.6, 5.5)	
Other[a]	0.3 (0.2, 0.5)	0.8 (0.3, 1.7)	0.3 (0.2, 0.5)	
Smoking intensity when smoked the most (%)				
< ½ pack per day	0.0 (0.0, 0.1)	0.3 (0.0, 0.9)	0.0 (0.0, 0.1)	χ^2 = 706.2 (<.001)
½–1 pack per day	58.1 (57.0, 59.1)	58.4 (54.9, 61.9)	37.8 (36.7, 38.9)	
>1 pack per day	41.9 (40.8, 43.0)	41.3 (37.9, 44.9)	62.2 (61.1, 63.3)	
Readiness to quit (range 1–9; mean, *SD*)	5.1 (1.5)	9.0 (1.1)	9.8 (0.8)	*F* = 29092.8 (<.001)
Fagerstrom Test for Nicotine Dependence when smoked the most (range 1–10; mean, *SD*)	5.4 (2.2)	5.2 (2.3)	5.5 (2.5)	*F* = 9.1 (.001)
Duration of smoking (years; mean, *SD*)	42.7 (6.5)	41.7 (6.6)	37.2 (7.1)	*F* = 1338.4 (<.001)
Duration of abstinence (years; mean, *SD*)	NA	NA	7.8 (4.7)	NA
Personal history of cancer other than lung cancer (% yes)	9.8 (9.1, 10.4)	9.9 (7.9, 12.2)	11.9 (11.2, 12.7)	χ^2 = 20.2 (<.001)
Personal history of smoking-related disease (% yes)	22.8 (21.9, 23.7)	26.2 (23.2, 29.4)	26.1 (25.2, 27.1)	χ^2 = 25.2 (<.001)
Family history of lung cancer (% yes)	22.4 (21.5, 23.3)	21.1 (18.3, 24.1)	24.6 (23.7, 25.6)	χ^2 = 13.7 (.001)
At least one false positive (%)				
LDCT arm	35.1 (33.7, 36.6)	25.8 (21.5, 30.3)	30.5 (29.0, 31.9)	χ^2 = 28.6 (<.001)
CXR arm	14.2 (13.2, 15.3)	13.2 (10.0, 17.0)	14.0 (12.9, 15.1)	χ^2 = 0.3 (.85)

LDCT = low-dose computed tomography.

[a]Includes missing, unknown, prefer not to answer.

Table 2. Annual Rates for Smoking Behaviors by Year

Year	Point (7-day) abstinence among smokers, *n* = 8358	Sustained (6-months) abstinence among smokers, *n* = 8358	Relapse among recently quit former smokers, *n* = 786	Relapse among long-term former smokers, *n* = 7820	Relapse among baseline smokers who quit during follow-up, *n* = 2549
	%	%	%	%	%
Year 1	11.6	4.1	50.9	4.2	30.9
Year 2	13.4	8.8	23.4	1.7	7.9
Year 3	11.7	8.2	4.1	0.8	2.7
Year 4	12.6	8.3	2.1	0.5	3.9
Year 5	11.9	10.1	2.3	0.3	0.9

most receptive to behavior change.[15,33] This is particularly important because as of January 1, 2015, the Patient Protection and Affordable Care Act requires that most health insurance plans cover tobacco cessation interventions as well as lung screening for high-risk individuals, including long-term, heavy smokers.[34]

Although initially increasing up-front costs, the boost in cessation due to the combination of screening and effective smoking cessation treatments may also reduce costs for annual lung screening below the $75 000 per quality-adjusted life year estimated by McMahon et al.[10] This would lead to dramatic savings in annual lung screening relative to the costs of $126 000–$169 000 per quality-adjusted life year projected by McMahon et al.[10] for annual screenings of current and former smokers aged 50–75 when compared to no screening and assuming general population quit rates. For example, Villanti and colleagues[35] estimated the cost-utility of annual, LDCT screenings over 15 years in a cohort of adults 50–64 years with at least a 30
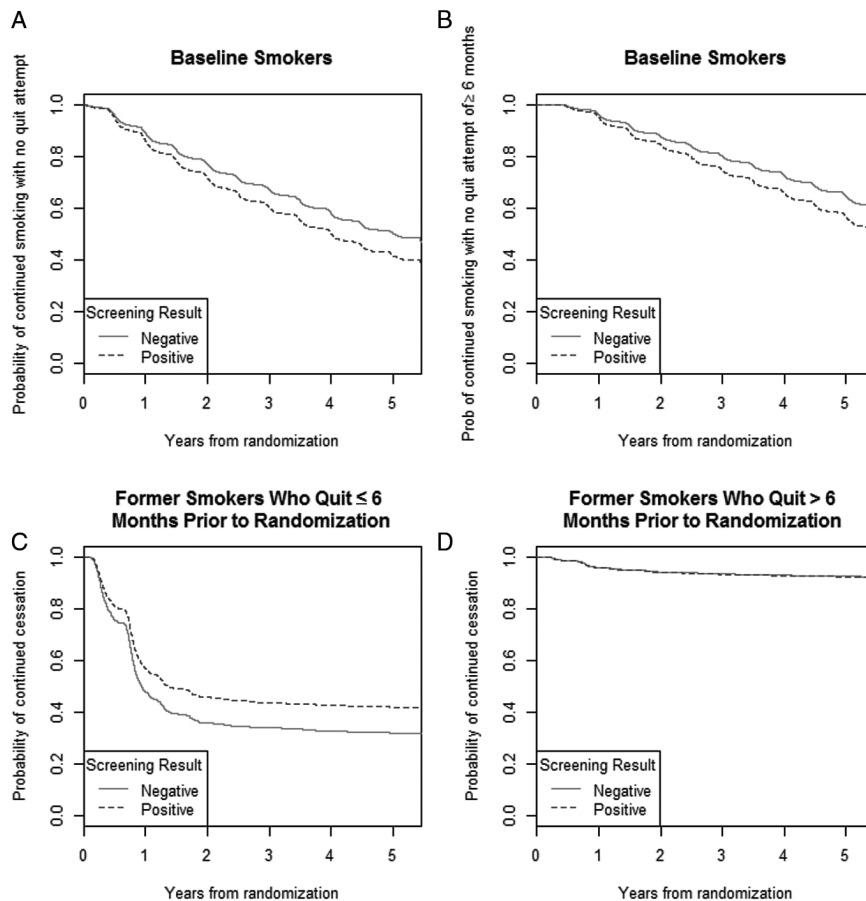
Figure 2. (a) Cox Regression estimates of time until baseline smokers made a quit attempt of any length by screening result. (b) Cox Regression estimates of time until baseline smokers made a quit attempt of 6 months or longer by screening result. (c) Cox Regression estimates of time until former smokers who quit ≤ 6 months prior to randomization (eg, recently quit former smokers) relapsed. (d) Cox Regression estimates of time until former smokers who quit >6 months prior to randomization (eg, long term former smokers) relapsed.

pack-year smoking history. In the base case, the cost-utility ratio was $28 240 per quality-adjusted life year. Adding smoking cessation to annual screenings resulted in cost-utility ratios ranging from $16 198–$23 185 per quality-adjusted life year depending on the intensity of the smoking cessation treatment used. Therefore, effective smoking cessation treatments coupled with screening would make cost effectiveness estimates for lung cancer screening more comparable to those of other population-based cancer screening programs (ie, colorectal and breast screening).[10,35]

A false positive screen was associated with higher point and sustained abstinence and is consistent with results presented by Tammemägi et al.[22] Individuals were most likely to make a cessation attempt after their first false positive screen. This is particularly noteworthy because all positive screens in these analyses were false positives. Therefore, individuals were ultimately told that they did not have a lung cancer. Furthermore, more than one false positive screening did not have a greater association with cessation than a single false positive screen, suggesting that the first communication of an abnormal screen result provides the most important trigger for motivating a cessation attempt. This is also one of a limited numbers of studies to document that a false positive screen was associated with an increase in readiness to quit smoking among baseline smokers with no quit attempts during the study period prior to the false positive result. A false positive screen may stimulate an increase in motivation to quit even if a smoker is not

yet prepared to make a quit attempt. Providing more intensive cessation counseling and resources at the time of a false positive screen may build on changes in motivation and translate to greater numbers of quit attempts and ultimately improved cessation rates.

Results from this study also suggest that participation in lung screening does not promote relapse among former smokers and may provide increased motivation for continued abstinence among high-risk former smokers. Only 7% of long-term former smokers at baseline relapsed during the 5-year study period. Relapse rates among baseline recent quitters and baseline smokers who quit for at least 6 months during the study period were 65% and 41%, respectively. These rates are comparable to relapse rates among former smokers in the general population[36] and to the results of other lung screening trials with more than two years of follow-up.[16,32] At least one false positive screening result was associated with lower likelihood of relapse among recent quitters, and a negative result was not associated with relapse among long-term former smokers or among smokers at baseline who quit during the study follow-up. Finally, we found no evidence that three consistently negative screening results were associated with relapse among former smokers. More data are needed to determine whether relapse rates among the majority of former smokers with negative screens would be comparable to those of individuals with false positive results if relapse prevention counseling was added to screening programs.

Although there were more false positive test results among individuals screened with the LDCT than CXR,[2] there were no differences in smoking outcomes by study arm after accounting for screening result. Because the majority of positive screens are false positives regardless of screening type, individuals may habituate to a positive result after their first experience with a false positive result.

This study has limitations. First, the applicability of the findings to other populations of current and former smokers may be limited. Individuals participating in a randomized trial of lung screening may differ from those screened in the general population. Participants were also more likely to identify as white race and to have more education than other general population samples of comparably-aged smokers.[37,38] Second, there was imprecision in the estimation of abstinence and relapse because participants were asked for their smoking status at each 6-month assessment interval rather than actual dates of changes in smoking status. Third, smoking data were based on self-administered questionnaires without biochemical verification. Some participants may have misreported smoking status; however, prior studies using biochemical verification suggest that self-reported smoking status among participants in lung screening trials is valid[39,40] and it is unlikely that social desirability bias would differ according to study arm or screening result.

Conclusion

Lung screening yields increases in smoking cessation, relapse prevention, and motivation for quitting that have important implications for population health. Adding proven and cost effective smoking cessation interventions, beyond the limited information provided in the NLST, could greatly enhance the impact of lung screening.[10] Smoking cessation resources targeted to current smokers and recent quitters can complement the "teachable moment" when screening results are provided to patients. Methods for the optimal integration of evidence-based smoking cessation with lung screening remain an important area for future research, practice and policy and would improve the cost-effectiveness of screening when integrated into the health care delivery system and the Patient Protection and Affordable Care Act.[10,40,41]

Supplementary Material

Supplementary Table A1 and Figure A1 can be found online at http://www.ntr.oxfordjournals.org

Funding

Declaration of Interests

None declared.

References

1. American Cancer Society. Cancer Facts and Figures. 2013. www.cancer.org/acs/groups/content/@epidemiologysurveilance/documents/document/acspc-036845.pdf. Accessed August 15, 2013.

2. Aberle DR, Adams AM, Berg CD, et al. Reduced lung-cancer mortality with low-dose computed tomographic screening. *N Engl J Med*. 2011;365(5):395–409. doi:10.1056/NEJMoa1102873.

3. American Lung Association. *Providing Guidance on Lung Cancer Screening To Patients and Physicians*. 2012. http://www.lung.org/lung-disease/lung-cancer/lung-cancer-screening-guidelines/lung-cancer-screening.pdf. Accessed August 21, 2013..

4. Bach PB, Mirkin JN, Oliver TK, et al. Benefits and harms of CT screening for lung cancer: a systematic review. *JAMA*. 2012;307(22):2418–2429. doi:10.1001/jama.2012.5521.

5. Detterbeck FC, Mazzone PJ, Naidich DP, Bach PB. Screening for lung cancer: diagnosis and management of lung cancer, 3rd ed: American College of Chest Physicians evidence-based clinical practice guidelines. *Chest*. 2013;143(suppl 5):e78S–92S. doi:10.1378/chest.12–2350.

6. Jaklitsch MT, Jacobson FL, Austin JH, et al. The American Association for Thoracic Surgery guidelines for lung cancer screening using low-dose computed tomography scans for lung cancer survivors and other high-risk groups. *J Thorac Cardiovasc Surg*. 2012;144(1):33–38. doi:10.1016/j.jtcvs.2012.05.060.

7. National Comprehensive Cancer Network (NCCN). *NCCN Clinical Practice Guidelines in Oncology: Lung Cancer Screening*. Fort Washington, PA: National Comprehensive Cancer Network; 2012.

8. US Preventive Services Task Force. Screening for Lung Cancer: U.S. Preventive Services Task Force Recommendation Statement. 2013. www.uspreventiveservicestaskforce.org/draftrec.htm#ref2. Accessed August 21, 2013.

9. Wender R, Fontham ET, Barrera E Jr, et al. American Cancer Society lung cancer screening guidelines. *CA Cancer J Clin*. 2013;63(2):107–117. doi:10.3322/caac.21172.

10. McMahon PM, Kong CY, Bouzan C, et al. Cost-effectiveness of computed tomography screening for lung cancer in the United States. *J Thorac Oncol*. 2011;6(11):1841–1848. doi:10.1097/JTO.0b013e31822e59b3.

11. Alberg AJ, Ford JG, Samet JM. Epidemiology of lung cancer: ACCP evidence-based clinical practice guidelines (2nd edition). *Chest*. 2007;132(suppl 3):29S–55S. doi:10.1378/chest.07-1347.

12. Centers for Disease Control and Prevention. Quitting smoking among adults—United States, 2001–2010. *MMWR Morb Mortal Wkly Rep*. 2011;60(44):1513–1519.

13. Cox LS, Clark MM, Jett JR, et al. Change in smoking status after spiral chest computed tomography scan screening. *Cancer*. 2003;98(11):2495–2501. doi:10.1002/cncr.11813.

14. Ostroff JS, Buckshee N, Mancuso CA, Yankelevitz DF, Henschke CI. Smoking cessation following CT screening for early detection of lung cancer. *Prev Med*. 2001;33(6):613–621. doi:10.1006/pmed.2001.0935.

15. Taylor KL, Cox LS, Zincke N, Mehta L, McGuire C, Gelmann E. Lung cancer screening as a teachable moment for smoking cessation. *Lung Cancer*. 2007;56(1):125–134. doi:10.1016/j.lungcan.2006.11.015.

16. Townsend CO, Clark MM, Jett JR, et al. Relation between smoking cessation and receiving results from three annual spiral chest computed tomography scans for lung carcinoma screening. *Cancer*. 2005;103(10):2154–2162. doi:10.1002/cncr.21045.

17. Ashraf H, Tonnesen P, Holst Pedersen J, Dirksen A, Thorsen H, Dossing M. Effect of CT screening on smoking habits at 1-year follow-up in the Danish Lung Cancer Screening Trial (DLCST). *Thorax*. 2009;64(5):388–392. doi:10.1136/thx.2008.102475.

18. van der Aalst CM, van den Bergh KA, Willemsen MC, de Koning HJ, van Klaveren RJ. Lung cancer screening and smoking abstinence: 2 year follow-up data from the Dutch-Belgian randomised controlled lung cancer screening trial. *Thorax*. 2010;65(7):600–605. doi:10.1136/thx.2009.133751.

19. Barry SA, Tammemagi MC, Penek S, et al. Predictors of adverse smoking outcomes in the Prostate, Lung, Colorectal and Ovarian Cancer Screening Trial. *J Natl Cancer Inst*. 2012;104(21):1647–1659. doi:10.1093/jnci/djs398.

20. Shi L, Iguchi MY. "Risk homeostasis"or "teachable moment"? the interaction between smoking behavior and lung cancer screening in the Mayo Lung Project. *Tob Induc Dis*. 2011;9(1):2. doi:10.1186/1617-9625-9-2.

21. van der Aalst CM, van Klaveren RJ, van den Bergh KA, Willemsen MC, de Koning HJ. The impact of a lung cancer computed tomography screening result on smoking abstinence. *Eur Respir J*. 2011;37(6):1466–1473. doi:10.1183/09031936.00035410.

22. Tammemagi MC, Berg CD, Riley TL, Cunningham CR, Taylor KL. Impact of lung cancer screening results on smoking cessation. *J Natl Cancer Inst*. 2014;106(6):dju084. doi:10.1093/jnci/dju084.

23. Aberle DR, Adams AM, Berg CD, et al. Baseline characteristics of participants in the randomized national lung screening trial. *J Natl Cancer Inst*. 2010;102(23):1771–1779. doi:10.1093/jnci/djq434.

24. Aberle DR, Berg CD, Black WC, et al. The National Lung Screening Trial: overview and study design. *Radiology*. 2011;258(1):243–253. doi:10.1148/radiol.10091808.

25. Gritz ER, Nisenbaum R, Elashoff RE, Holmes EC. Smoking behavior following diagnosis in patients with stage I non-small cell lung cancer. *Cancer Cause Control*. 1991;2(2):105–112. doi:10.1007/BF00053129.

26. Twardella D, Loew M, Rothenbacher D, Stegmaier C, Ziegler H, Brenner H. The diagnosis of a smoking-related disease is a prominent trigger for smoking cessation in a retrospective cohort study. *J Clin Epidemiol*. 2006;59(1):82–89. doi:10.1016/j.jclinepi.2005.05.003.

27. Walker MS, Vidrine DJ, Gritz ER, et al. Smoking relapse during the first year after treatment for early-stage non-small-cell lung cancer. *Cancer Epidemiol Biomarkers Prev*. 2006;15(12):2370–2377. doi:10.1158/1055–9965.EPI-06-0509.

28. Biener L, Abrams DB. The Contemplation Ladder: validation of a measure of readiness to consider smoking cessation. *Health Psychol*. 1991;10(5):360–365. doi:10.1037/0278-6133.10.5.360.

29. Heatherton TF, Kozlowski LT, Frecker RC, Fagerstrom KO. The Fagerstrom Test for Nicotine Dependence: a revision of the Fagerstrom Tolerance Questionnaire. *Brit J Addict*. 1991;86(9):1119–1127. doi:10.1111/j.1360-0443.1991.tb01879.x.

30. Fiore MC, Jaen CR. A clinical blueprint to accelerate the elimination of tobacco use. *JAMA*. 2008;299(17):2083–2085. doi:10.1001/jama.299.17.2083.

31. Fiore MC, Jaén CR, Baker TB, et al. Treating Tobacco Use and Dependence: 2008 Update. In: U.S. Department of Health and Human Services, Public Health Service ed. *Clinical Practice Guideline*. Rockville, MD: U.S. Department of Health and Human Services, Public Health Service; 2008.

32. Anderson CM, Yip R, Henschke CI, Yankelevitz DF, Ostroff JS, Burns DM. Smoking cessation and relapse during a lung cancer screening program. *Cancer Epidemiol Biomarkers Prev*. 2009;18(12):3476–3483. doi:10.1158/1055–9965.EPI-09-0176.

33. McBride CM, Emmons KM, Lipkus IM. Understanding the potential of teachable moments: the case of smoking cessation. *Health Educ Res*. 2003;18(2):156–170. doi:10.1093/her/18.2.156.

34. United States Department of Labor. FAQs about Affordable Care Act Implementation (Part XIX). 2014. www.dol.gov/ebsa/faqs/faq-aca19.html. Accessed November 28, 2014.

35. Villanti AC, Jiang Y, Abrams DB, Pyenson BS. A cost-utility analysis of lung cancer screening and the additional benefits of incorporating smoking cessation interventions. *PLoS One*. 2013;8(8):e71379. doi:10.1371/journal.pone.0071379.

36. Wetter DW, Cofta-Gunn L, Fouladi RT, Cinciripini PM, Sui D, Gritz ER. Late relapse/sustained abstinence among former smokers: a longitudinal study. *Prev Med*. 2004;39(6):1156–1163. doi:10.1016/j.ypmed.2004.04.028.

37. Kahende JW, Malarcher AM, Teplinskaya A, Asman KJ. Quit attempt correlates among smokers by race/ethnicity. *Int J Environ Res Public Health*. 2011;8(10):3871–3888. doi:10.3390/ijerph8103871.

38. Messer K, Trinidad DR, Al-Delaimy WK, Pierce JP. Smoking cessation rates in the United States: a comparison of young adult and older smokers. *Am J Public Health*. 2008;98(2):317–322. doi:10.2105/AJPH.2007.112060.

39. Studts JL, Ghate SR, Gill JL, et al. Validity of self-reported smoking status among participants in a lung cancer screening trial. *Cancer Epidemiol Biomarkers Prev*. 2006;15(10):1825–1828. doi:10.1158/1055–9965.EPI-06-0393.

40. Abrams D. Comprehensive smoking cessation: systems integration to save lives and money. In: Bonnie RJ, Stratton KA, Wallace RB eds. *Ending the Tobacco Problem: A Blueprint for the Nation*. Washington, DC: The National Academies Press; 2007:A1–A50.

41. Smith RA, Brooks D, Cokkinides V, Saslow D, Brawley OW. Cancer screening in the United States, 2013: a review of current American Cancer Society guidelines, current issues in cancer screening, and new guidance on cervical cancer screening and lung cancer screening. *CA Cancer J Clin*. 2013;63(2):88–105. doi:10.3322/caac.21174.