Practice of Epidemiology

Validation of a Method for Reconstructing Historical Rates of Smoking Prevalence

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The validity of methods for reconstructing historical rates of smoking prevalence has not been assessed before. Our objective was to assess their validity. We reconstructed smoking prevalence rates for each calendar year from 1940 to 2007 for men and women in Spain, using data on ages of smoking initiation and cessation available in the Spanish National Health Surveys of 2003–2004 and 2006–2007. To assess the validity of the reconstruction, we computed the differences between the reconstructed smoking prevalence and the contemporary observed smoking prevalence measured in the Spanish National Health Surveys of 1987, 1993, 1995, 1997, and 2001. We also compared reconstructed smoking prevalence trends with 35-year lagged lung cancer mortality rates in Spain as a proxy for the real prevalence trends. Reconstructed smoking prevalence rates compared with contemporary measured rates showed small differences in men (between −2.1% and 2.1%) and an overestimation in women (between 2.0% and 5.7%). Reconstructed smoking prevalence trends were significantly correlated with lagged lung cancer mortality trends (P = 0.004 for men, P < 0.0001 for women). The reconstruction of smoking prevalence rates through this methodology offers a feasible tool with which countries lacking previous smoking surveys can understand historical trends in their tobacco epidemic, which aids in designing and implementing adequate tobacco control interventions.

developing countries; prevention and control; smoking; statistical models; validation studies

The prevalence of tobacco smoking is usually measured through population-based surveys, relying on self-reported information. At the same time, only a few countries, such as the United States, have conducted population-based self-report surveys since the middle of the 20th century. (In the United States, the National Health Interview Survey (http://www.cdc.gov/nchs/nhis.htm), first conducted in 1957, is conducted on a yearly basis.) Most developed countries did not conduct population-based surveys during the peak of the tobacco smoking epidemic, and developing countries, which are usually in earlier stages of the epidemic, have only recently conducted population-based health surveys.

A model of the tobacco epidemic was published by Lopez et al. (1) in 1994. Lopez et al. proposed a 4-stage model following smoking prevalence rates and smoking-attributable mortality rates. They aimed at describing the dynamics of smoking in order to better understand future trends. The model was based on the assumption that smoking-attributable mortality (especially that occurring at ages 35–69 years) follows smoking prevalence rates with a given lag, generally about 30–40 years (1). The model was recently updated in 2012 (2), with specific gender trends in order to better reflect the different gender-related smoking dynamics in each country.

Reconstruction methods have been developed to characterize the stages of the tobacco epidemic in the last century (3–6). These methods allow reconstruction of smoking prevalence rates in previous decades using information available from current health surveys, allowing examination of the historical development of the tobacco epidemic and the study of smoking initiation and cessation patterns. It is necessary to reconstruct smoking prevalence rates for a given country in order to plan and evaluate tobacco control policies and interventions.
Our aim in the current study was to assess the validity of an epidemiologic method for reconstructing historical rates of smoking prevalence in Spain.

MATERIALS AND METHODS

Study population

Data were obtained from 7 administrations of the National Health Survey (Encuesta Nacional de Salud), conducted in Spain at nonregular intervals between 1987 and 2007 (http://www.ine.es). These cross-sectional surveys included representative samples of the noninstitutionalized Spanish population. Sample sizes were 29,647 in 1987; 21,120 in 1993; 5,998 in 1995; 21,120 in 2001; 21,650 in 2003–2004; and 29,478 in 2006–2007. All surveys included information on smoking status, and starting in 1993, they also included information on number of cigarettes smoked per day, age at smoking initiation (for current and former smokers), and age at smoking cessation (for former smokers). For this study, we considered all interviewed subjects with full information on smoking status, and starting in 1993, they also included information on number of cigarettes smoked per day, age at smoking initiation (for current and former smokers), and age at smoking cessation (for former smokers). For this study, we considered all interviewed subjects with full information on smoking history. We excluded those who smoked only cigars or pipes (less than 1% of the smoking population).

Reconstruction method

Using a method described previously (3–6), we reconstructed the smoking prevalence rate for each calendar year from 1940 to 2007, using data from the 2 latest available surveys, conducted in 2003–2004 and 2006–2007. To obtain the number of smokers, we assigned each survey participant a smoking status (smoker/non-smoker) for each calendar year in which the participant was aged 16 years or older. Never smokers were considered nonsmokers for the whole period. Current smokers were considered smokers from the year of initiation to their current age. Former smokers were considered smokers from the year of smoking initiation to the year of cessation and were considered nonsmokers before initiation and from the age of cessation onward. We pooled data from the 2 surveys (2003–2004 and 2006–2007) and calculated the smoking prevalence for each calendar year by dividing the number of smokers by the total population aged 16 years or more in that calendar year. Given the complex survey design (multistage and stratified), each observation had a probability sampling weight that took the survey design into account. These weights were employed in our analysis using the survey estimation tools in STATA (StataCorp LP, College Station, Texas), the svy commands. These commands automatically provide standard errors incorporating the survey design (7). In order to pool results from the 2 surveys while keeping the survey design caveats intact, we constructed 2 new variables with the interaction between the stratum or the primary sampling unit and the survey wave and used these 2 new variables (stratumXwave and primary sampling unitXwave) as the stratum/primary sampling unit indicators.

Mortality correction

Given the higher mortality rates among smokers, a mortality adjustment may be warranted to avoid underestimating rates of smoking prevalence. This mortality adjustment method has been described in detail previously (6). Life-table data were obtained from the Spanish National Institute of Statistics (http://www.ine.es) and from the Human Mortality Database (8). Excess mortality ratios for smokers were obtained from the latest available smoking and mortality cohort studies for men (9) and women (10). Men aged ≤54 years, 55–74 years, and ≥75 years were assigned excess mortality ratios of 2.05, 2.33, and 2.17, respectively (9). Women aged ≤59 years, 60–69 years, and ≥70 years were assigned excess mortality ratios of 2.60, 2.81, and 2.83, respectively (10).

Validity assessment

To assess the validity of this reconstruction method, we compared the contemporary smoking prevalence for each of the survey years (1987, 1993, 1995, 1997, and 2001) with the reconstructed prevalence rates for those years. We performed a 2-sample proportion test to check for a statistically significant difference between the reconstructed prevalence and the contemporary observed prevalence.

Given the lack of reliable smoking prevalence data in Spain before the year 1987, we also compared reconstructed prevalence rates with lung cancer mortality rates (as a proxy for smoking-attributable mortality) for persons aged 35–69 years, considering a 35-year lag, under the assumption that, for each gender, both prevalence rates and attributable mortality follow the recently updated tobacco epidemic model (2). We age-adjusted the lung cancer mortality rates using the direct standardization method and the European World Health Organization Standard Population (for age groups 35–69 years). We calculated Spearman’s correlation coefficients for correlations between the reconstructed prevalence rates and the lung cancer mortality rates 35 years forward to check for significant correlation in the trends of both rates.

Sensitivity analysis

As noted above, we used excess mortality ratios obtained from cohort studies from the United Kingdom (9, 10) for our mortality correction. Given the uncertainty about the validity of extrapolating these excess mortality ratios to Spain, we performed sensitivity analyses using different excess mortality ratios (in whole- and half-digit increments above and below the values specified; e.g., we calculated smoking prevalence rates using 1.05, 1.55, 2.05 (original), 2.55, and 3.05 as the excess mortality ratios for men under 55 years of age). We checked for differences between the original correction and the new corrections using a 2-sample proportion test.

We decided to use 2 surveys in order to increase the statistical power of our findings, especially on the earlier periods of our reconstruction. Given the possible absence of 2 national health surveys in certain countries, we performed a sensitivity analysis reconstructing and validating smoking prevalence rates using only 1 survey (the 2003–2004 survey or the 2006–2007 survey). In order to compare these 2 consecutive surveys, we performed a 2-sample proportion test to determine whether both reconstructions returned equal prevalence rates.

As described above, we used a 35-year lag to compare reconstructed prevalence rates and lung cancer mortality rates. Given
the uncertainty in the determination of the correct lag between smoking and its harmful effects, we conducted sensitivity analyses by switching this lag to 25, 30, 35, 40, and 50 years and checking whether the comparison in trends was still significant.

All analyses were stratified by gender and were performed using STATA SE, version 12.1. *P* values were 2-sided, and statistical significance was defined as *P* < 0.05.

**RESULTS**

**Smoking prevalence rates**

Figure 1 shows the reconstructed smoking prevalence rates for Spain from 1940 through 2007, by gender. In men, smoking prevalence was already above 54% in 1940 and slowly increased up to 61.3% in 1973, remaining stable at those levels up to 1980, when it started to decrease, from 58.5% in 1980 to 41.8% in 2000. This decreasing trend was accentuated between 2000 and 2007, from 41.8% to 21.9%. In women, smoking prevalence showed that, in men, the differences in the years 1973–1980 (from 6.0% in 1965 to 15.3% in 1975 and 26.5% in 1990). Women’s smoking prevalence leveled off at approximately 26% until the early 2000s, when it started to decrease slowly, from 26.7% in 2000 to 21.9% in 2007.

**Mortality correction**

Correction of the smoking prevalence rates by the excess mortality rates for smokers showed that, in men, the differences were appreciable only during the first decades of the study (1940–1960). The differences between the mortality-corrected and uncorrected reconstructed smoking prevalence rates were significant only before 1947 (*P* < 0.05), with differences ranging from −3% (in 1947) to −8% (in 1941). In women, the differences were negligible overall, not being significant in any year of the study (see Web Figure 1, available at http://aje.oxfordjournals.org/).

**Validity assessment using contemporary surveys**

To validate the reconstruction method, we compared contemporary smoking prevalence rates measured by the different national surveys with the reconstructed prevalence rates. Differences in contemporary observed and reconstructed prevalence rates in men ranged between −2.1% and 2.1%. This difference was statistically significant in 1987 (*P* = 0.004) and 1993 (*P* = 0.006) and was statistically null in 1995 (*P* = 0.13), 1997 (*P* = 0.06), and 2001 (*P* = 0.99) (Figure 1). In women, the reconstructed prevalence was significantly overestimated in all years, with differences ranging from 2.0% in 1995 to 5.7% in 1993.

**Validity assessment using lung cancer mortality rates**

Given the lack of contemporary surveys before 1986, we compared the trends in reconstructed smoking prevalence rates with the trends in age-adjusted lung cancer mortality rates for persons aged 35–69 years (Figure 2). We found that, with a 35-year lag between smoking and lung cancer mortality, men’s smoking prevalence was moderately (*r* = 0.47) and significantly (*P* = 0.004) correlated with lung cancer mortality rates. Women’s smoking prevalence was highly (*r* = 0.69) and significantly (*P* < 0.0001) correlated with lung cancer mortality rates.

**Sensitivity analyses**

We conducted the first sensitivity analyses after testing whether the excess mortality ratios had a large impact on reconstructed smoking prevalence rates (Web Figure 1). In all cases, the corrected reconstructed smoking prevalence rates were higher (as expected) than the uncorrected rates, and these differences increased as the excess mortality ratio for smokers increased. The difference between the original smoking prevalence rates and the rates obtained using the new ratios was not statistically significant for any year in either gender.

We conducted a second sensitivity analysis, reconstructing the smoking prevalence rates using 1 survey (either the 2003–2004 survey or the 2006–2007 survey) instead of 2 (Web Figure 2). The reconstructed smoking prevalence rates followed similar trends, showing, for men, statistically significant differences in the years 1973–1975 (*P* = 0.007, *P* = 0.01, and *P* = 0.01 respectively), 1984 and 1985 (*P* = 0.007 and *P* = 0.008, respectively), and 1993–2003 (*P* < 0.05 in all years). In the case of women, the differences were statistically significant during the years 1960–1975 (*P* < 0.05 in all years) and the years 2001–2003 (*P* = 0.01, *P* = 0.003, and *P* = 0.0004, respectively). The validation followed similar patterns in both validity assessment methods (contemporary surveys and lung cancer mortality rates). The only major change observed was related to an increase in the standard errors for the smoking prevalence rates, a change that was expected given the reduction in the sample size by using only 1 survey as compared with 2.

In the third sensitivity analysis we conducted, we switched the expected lag between reconstructed smoking prevalence rates and lung cancer rates from 35 years to 25, 30, 40, and 45 years. In the case of men, the highest correlation between
reconstructed smoking prevalence rates and lung cancer mortality rates was found with a lag of 25 years ($r = 0.80$). In the case of women, the highest correlation was found with a lag of 40 years ($r = 0.95$).

**DISCUSSION**

Comparing contemporary observed smoking prevalence rates with those obtained using an established reconstruction method (3–6) showed that it is possible to obtain smoking prevalence rates in a given country for a number of past decades, even in the absence of nationally representative data over those decades. Smoking patterns in the last 70 years in Spain were coherent with the theoretical model of the tobacco epidemic (2), showing the same phases this model predicts.

The mortality correction we performed showed small changes, even in the absence of nationally representative data over those decades and their higher mortality rates. Given the multiplicative effect of the excess mortality ratio, this method has a larger effect during eras of higher mortality (such as the first decades of the study). On the other hand, women had very low smoking prevalence rates in those decades, and therefore the effect of the mortality correction was very small. In summary, the mortality correction did not have a major impact on the reconstructed smoking prevalence rates in the last decades of the study in men, and it had no effect whatsoever in women.

Therefore, and given the complexity of the mortality correction method, we would recommend against performing the mortality correction in studies that aim at reconstructing recent smoking prevalence rates.

The accuracy of the model established by comparison with contemporary surveys was better for men than for women, where we found a consistent overestimation of smoking prevalence rates by our method. The differences in the reconstructed prevalences versus the contemporary measured smoking prevalences ranged between −2.1% and 2.1% for men, with results from 3 out of 5 statistical tests being nonsignificant for differences. These differences were larger for women, ranging between 2.0% and 5.1%, and results were statistically significant for all 5 tests. These gender differences were not explained by differential mortality or by differences in survey methods and could be related to reporting bias among women. This finding for reconstructed smoking prevalence rates versus observed contemporary smoking prevalence rates may be traced back to a differential information bias. The prevalences obtained from contemporary surveys may be differentially biased for men and women. Given the social stigma associated with smoking (11) and the late adoption of smoking by women (12), women may have underreported their smoking status in the original contemporary surveys when compared with men.

The accuracy of the model (from 1940 to 1986) assessed by comparing reconstructed smoking prevalence rates with lagged lung cancer mortality rates was better for women than for men. Sensitivity analyses found that the lag that leads to the best correlation is different for men (25 years) and women (40 years). Overall, it seems that this reconstruction method offers a valid tool with which to study historical smoking dynamics, whereas it does not provide exact prevalence numbers.

The present study had several limitations. First, it relied on self-reported smoking status. Nonetheless, previous reports have underlined the accuracy of self-reported measurements of smoking prevalence (13). Second, while the reconstruction spanned the period 1940–2003, the data points used for inference-drawing referred only to the period 1987–2003. We tried compensating for this limitation by comparing reconstructed smoking rates with a proxy for smoking-attributable mortality: lung cancer mortality rates for persons aged 35–69 years. This method has been used before to model the tobacco epidemic in several countries (2). Third, the mortality correction may not have accurately reflected the excess mortality experienced by smokers. The excess mortality ratios used in our study were calculated in cohort studies from the United Kingdom, which may not entirely be applicable to Spain, where cohort studies regarding smoking mortality are nonexistent. Nonetheless, the sensitivity analyses we carried out by using different excess mortality ratios did not show major differences. Fourth, some of our results may be reliant on the large sample size, given that we used 2 surveys. Sensitivity analyses using 1 single survey showed no difference.
Method for Reconstructing Smoking Prevalence Rates

Possible strengths of the study include 1) the sample selection method (nationally representative surveys using a complex survey design, stratified and multistage); which we took into account in our analysis; 2) the large sample size in each survey, with over 120,000 participants for all surveys, allowing for sample sizes large enough to calculate the statistical validity of the method through the comparison of point prevalences and trends over time; and 3) the simplicity of the reconstruction method, which can be performed by other research and public health groups with no complicated statistical tools.

This reconstruction method offers a feasible tool with which investigators in countries without historical smoking surveys can better understand the dynamics of the tobacco epidemic within their populations. Given the feasibility of conducting a health survey in a nationally representative sample, we are convinced that this is an affordable method developing countries can use to obtain reliable data on historical trends in smoking in their populations. While this method may not ultimately generate an accurate smoking prevalence rate for a given year (especially for women), it provides valid and useful information on historical smoking trends.

Variations in smoking prevalence due to changing social norms can also be studied by means of this reconstruction method. Given the important role of gender in smoking, knowing the specific dynamics of tobacco use in women is of great preventive relevance (14). Additional information on socio-demographic and socioeconomic factors included in comprehensive health surveys can also help identify trends in vulnerable groups from a tobacco control perspective (such as adolescents or persons of low socioeconomic status). Historical information on smoking prevalence and trends is a necessary tool that can assist policy-makers and public health authorities in tackling the tobacco epidemic.

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