Optimum Cutoff Points for Biochemical Validation of Smoking Status

STEVEN R. CUMMINGS, MD, AND ROBERT J. RICHARD, MA

Abstract: Selection of cutoff points for tests to validate smoking cessation should take account of the prevalence of deception. When the prevalence of deception is relatively low, the cutoff points to validate quitting should be relatively high. Many studies have used cutoff points that are too low and may have underestimated cessation rates. We present a method for determining the best cutoff points that takes account of the prevalence of deception. (*Am J Public Health* 1988; 78:574–575.)

Introduction

Studies of smoking cessation often use biochemical tests to "validate" self-reported cessation. Self-reported quitters with levels above certain cutoff values are called "deceivers" and are counted as smokers.

Just as the predictive value of a diagnostic test depends on the prevalence of the disease in a population,[1] the accuracy of tests to validate smoking cessation depends on the prevalence of smoking (or deception) in the population tested. We developed a method for determining the best cutoff points for tests to validate smoking status that takes account of this principle.

Methods

Biochemical Measurements

We used data from Jarvis, *et al*,[2] who ascertained self-reported smoking and then obtained samples of urine, saliva, blood, and expired air from 215 London outpatients. By self-report, 90 (43 per cent) were current smokers, but 21 "nonsmokers" were reclassified as smokers because of substantially elevated values of biochemical tests (mean plasma cotinine = 239 ng/ml).

Defining the Ideal Cutoff Point

The best cutoff point is one that minimizes the number of subjects misclassified. The number of subjects misclassified (N errors) is a function of the false-negative rate (FNR) and false-positive rate (FPR) of the test at that cutoff value *and* the prevalence of smoking (p) in the population that is being tested:

$$N \text{ errors} = p\,(FNR - FPR) + FPR \quad \text{(equation 1)}$$

Thus, when the prevalence of smoking is low, the total number of misclassifications depends primarily on the false-positive rate.

Using original data from Jarvis,[2] we calculated the true- (TPR) and false-positive rates for each test for a range of possible cutoff values. We used their final assignment of smoking status[2] as the "gold standard." We derived logistic models for smoothed relationships between true-positive rates, true-negative rates (TNR) and cutoff values:

$$\ln\left(\frac{TPR}{1 - TPR}\right) = a + b \ln(\text{cutoff})$$

and,

$$\ln\left(\frac{TNR}{1 - TNR}\right) = c + d \ln(\text{cutoff})$$

We used the least squares method in Eureka: The Solver, a numerical analysis program, to estimate coefficients of the models from the Jarvis data. The "best" cutoff values were calculated from equation 1 for prevalences of smoking ranging from 5 to 50 per cent.

Results

The best cutoff points for various tests depend on the prevalence of smoking in the group being tested (Table 1). The lower the prevalence, the higher the best cutoff value.

The prevalence of smoking has a greater influence on the choice of cutoff points for tests, like expired carbon monoxide (CO) that have substantial overlap between smokers and nonsmokers and less influence on cutoff points for more accurate tests, such as plasma cotinine (Table 1).

TABLE 1—Optimal Cutoff Points for Biochemical Tests of Smoking at Various Prevalences of Smoking

Test	Prevalence of Smoking	Optimal Cutoff*	Estimated† Error Rate (%)
Expired CO (ppm)	.05	16	2.9
	.10	14	4.7
	.20	12	7.2
	.50	9	10.8
Carboxyhemoglobin (%)	.05	2.8	2.6
	.10	2.4	4.1
	.20	2.0	6.3
	.50	1.6	9.7
Plasma Thiocyanate (μmol/l)	.05	153	4.5
	.10	119	7.3
	.20	98	10.8
	.50	75	14.4
Saliva Thiocyanate (μmol/l)	.05	4.45	8.9
	.10	4.45	13.3
	.20	2.40	21.8
	.50	1.47	22.2
Plasma Cotinine (ng/ml)	.05	14	1.7
	.10	14	1.8
	.20	14	2.1
	.50	13	2.9
Saliva Cotinine (ng/ml)	.05	46	0.4
	.10	35	0.6
	.20	26	1.1
	.50	15	2.0
Plasma Nicotine (ng/ml)	.05	7.8	2.1
	.10	5.7	3.4
	.20	4.2	5.1
	.50	2.4	7.7
Saliva Nicotine (ng/ml)	.05	52	1.7
	.10	48	2.7
	.20	34	4.1
	.50	18	6.5

*Based on data from a study by Jarvis[2]

†Defined as: $\frac{\text{Total number of false positive and false negative misclassifications}}{\text{Total number of subjects tested}}$

From the Division of General Internal Medicine (both authors) and the Clinical Epidemiology Program (Dr. Cummings), University of California at San Francisco. Address reprint requests to Steven R. Cummings, MD, Box 0320, University of California, San Francisco, CA 94143. This paper, submitted to the Journal August 4, 1987, was revised and accepted for publication November 3, 1987.

Discussion

The best cutoff values for biochemical tests to define smoking status depend on the prevalence of smoking in the population tested. When the prevalence is relatively low, the number of misclassifications will depend primarily on the false-positive rate of the test (equation 1). Thus, the optimum cutoff should be higher to minimize the false-positive rate.

The prevalence of deception among self-reported nonsmokers and smokers who claim to have quit is generally less than 25 per cent.[3-7] Therefore, when these tests are used to "validate" self-reported cessation, the best cutoff values for biochemical tests may be higher than have been recommended and used in previous studies.[8-12]

For example, the cutoff values used for expired CO generally range from 6 to 10 ppm. If expired CO is measured in 100 subjects who claim to quit smoking but 10 (10 per cent) are actually smokers, a cutoff point of 7 ppm would misclassify 23 people (Table 2): 22 nonsmokers misclassified as smokers and one smoker misclassified as a nonsmoker. However, for a 10 per cent prevalence of smoking, the ideal cutoff value is 14 ppm (Table 1). Using this higher cutoff value would misclassify only five people: two nonsmokers misclassified as smokers, and three smokers misclassified as nonsmokers.

Inappropriately low cutoff values may have affected the results of some previous studies. For example, in a controlled trial of the effectiveness of physicians' advice, Russell and colleagues[3] used a cutoff of 7 ppm for expired CO and, on this basis, reclassified 22 per cent of self-reported quitters as deceivers. Our analysis suggests that the cutoff point was too low and most of the "deceivers" were nonsmokers with false positive tests. A higher cutoff value that was more appropriate for the prevalence of deception may have reduced the number of misclassifications and resulted in higher "validated" cessation rates.

In selecting cutoff points for validating cessation, it seems reasonable to assume that deception rates will be less than 25 per cent among subjects who claim to have quit smoking.[3-7] When deception rates are similar in control and experimental groups, changes in cutoff values may have little effect on the conclusions of a controlled trial. However, using more appropriate cutoff points will produce more accurate estimates of cessation rates.

Recommendations of lower cutoff values[8-12] have been based on studies with at least a 50 per cent prevalence of smoking. For example, Vesey[10] studied 79 nonsmokers and 360 smokers (82 per cent prevalence) and recommended cutoffs of 73 pg/ml for plasma thiocyanate and 1.6 per cent for carboxyhemoglobin. These values may be appropriate when the prevalence of smoking exceeds 50 per cent (Table 1), but not when the prevalence is lower.

The Jarvis study[2] has limitations that might affect our recommended cutoff values. Results of biochemical tests were used to reclassify 21 "nonsmokers" as smokers. This might have inflated the apparent accuracy of the tests. The data are from medical outpatients in London and data from different types of populations might produce somewhat different ideal cutoff values.

Furthermore, this method does not apply to surveys to estimate the prevalence of smoking in a population. In such surveys, the best cutoff points are those that produce an equal number of false negatives and false positives.

In conclusion, the best cutoff points for biochemical tests to validate smoking cessation depend on the prevalence of deception in the group to be tested. This effect is particularly important for tests, like expired carbon monoxide, with substantial overlap between the values of smokers and nonsmokers. Cutoff points used in past studies may have been too low and may have underestimated actual cessation rates. Selection of cutoff points for tests to validate smoking cessation should take account of the estimated prevalence of deception in the subjects tested.

TABLE 2—Estimated Misclassification of Smokers and Nonsmokers at Different Cutoff Values for Expired CO and Prevalences of Smoking (Per Cent Misclassified)

Cutoff Value (ppm)	Prevalence of Smoking		
	.05	.10	.20
6	38.1	36.3	32.7
7	24.2	23.2	21.3
8	15.3	15.0	14.3
9	10.0	10.1	10.3
10	6.9	7.4	8.3
12	4.1	5.1	7.2*
14	3.1	4.7*	7.8
16	2.9*	5.0	9.1
18	3.0	5.5	10.6

*Optimal cutoff point for this prevalence

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