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Using breath carbon monoxide to validate self-reported tobacco smoking in remote Australian Indigenous communities

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Abstract

Background: This paper examines the specificity and sensitivity of a breath carbon monoxide (BCO) test and optimum BCO cutoff level for validating self-reported tobacco smoking in Indigenous Australians in Arnhem Land, Northern Territory (NT).

Methods: In a sample of 400 people (≥16 years) interviewed about tobacco use in three communities, both self-reported smoking and BCO data were recorded for 309 study participants. Of these, 249 reported smoking tobacco within the preceding 24 hours, and 60 reported they had never smoked or had not smoked tobacco for ≥6 months. The sample was opportunistically recruited using quotas to reflect age and gender balances in the communities where the combined Indigenous populations comprised 1,104 males and 1,215 females (≥16 years). Local Indigenous research workers assisted researchers in interviewing participants and facilitating BCO tests using a portable hand-held analyzer.

Results: A BCO cutoff of ≥7 parts per million (ppm) provided good agreement between self-report and BCO (96.0% sensitivity, 93.3% specificity). An alternative cutoff of ≥5 ppm increased sensitivity from 96.0% to 99.6% with no change in specificity (93.3%). With data for two self-reported nonsmokers who also reported that they smoked cannabis removed from the analysis, specificity increased to 96.6%.

Conclusion: In these disadvantaged Indigenous populations, where data describing smoking are few, testing for BCO provides a practical, noninvasive, and immediate method to validate self-reported smoking. In further studies of tobacco smoking in these populations, cannabis use should be considered where self-reported nonsmokers show high BCO.

Introduction

Over the past two decades, smoking rates in Australia have halved in the general population from 35% to 18% with predictions of 14% by 2020[1]. However, for Indigenous Australians, smoking rates appear to have remained unchanged. Nationally, 51% of Indigenous men and 47% of Indigenous women report to be regular smokers[2].Smoking rates vary across Indigenous Australian populations. For example, much higher rates of between 59% to 83%[3-8] have been documented in some remote communities of the Northern Territory (NT), with up to 92% of people reporting a history of tobacco use in one community[3].

Indigenous Australians experience a burden of disease 2.4 times that of non-Indigenous Australians[9], with the gap between Indigenous and non-Indigenous life expectancy at birth in 2009 estimated to be 11.5 years for men and 9.7 years for women[10]. About 12% of the burden of disease[9] and 20% of indigenous deaths[11] are attributable to tobacco use. In 2008, the Australian government made a commitment to "closing the gap" in Indigenous Australian life expectancy[12], including addressing smoking[13].

Documenting tobacco use in Indigenous communities has typically relied on self-report in surveys, with a few

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studies using biochemical markers to verify self-report. Urine cotinine has been used in both urban[14] and remote clinic-based studies[7]. However, this involves the complexities and cost of obtaining and testing a urine sample and does not provide an immediate assessment of smoking. Portable, hand-held Breath Carbon Monoxide (BCO) analyzers are tools used to immediately assess smoking status. They are suitable for both clinical and community-based studies[15-23] and are being used in a small number of Indigenous Australian settings[24-26]. The utility of BCO analyzers and optimum BCO cutoff to distinguish smokers and nonsmokers is being investigated in different populations around the world[27-36] with different cutoff levels recommended in different populations dependent on the intended use of the BCO test. These include: assessing antenatal smoking[15,16,36]; clinical or community surveys[17,22,27-29,32,33,37]; validating smoking cessation [18,20,30]; assessing passive smoking[17] or environmental pollution[35]; or investigating sociocultural patterns of smoking[23]. There is, however, no guidance for the optimum BCO cutoff level to validate self-reported tobacco smoking in community-based surveys in Indigenous Australian populations.

This paper examines the sensitivity and specificity of the BCO test and the optimal cutoff level to distinguish between smokers and nonsmokers in three remote Indigenous populations.

Methods

Setting

The study was conducted in three Arnhem Land communities with a combined Indigenous population of 3,770, including 1,104 males and 1,215 females aged ≥16 years. Contemporary life is strongly influenced by traditional social and cultural norms and practices, with more than 20 tribal groups and seven major language groups represented across the three communities[38]. English is a second or third language[39]. Tobacco was introduced in the 17th century by Macassan traders from the Indonesian archipelago, and extended with the expansion of the pastoral industry and Christian missions during the early 20th century[40].

Sampling

Between July 2008 and February 2009, 400 Indigenous people (aged ≥16), comprising 15% of the targeted population, were interviewed in the baseline phase of a community-based intervention study.

Local community members were employed as research workers to assist in the recruitment of participants, to interpret when local language was required, and to assist with BCO testing. Given that random sampling is impractical and intrusive in these communities[41], participants were opportunistically invited to participate using quotas to reflect age and gender balances. Interviews occurred in public spaces or in people's homes.

Community Survey: Self-reported tobacco smoking and BCO

Using a structured questionnaire, participants were asked about smoking status, smoking history, and pattern of tobacco use. Interviews were conducted by authors DM, JR, and AC, in most cases with local research workers. Participants were asked: "Do you smoke tobacco?" If the participant answered yes, a series of questions including the type of tobacco product used, the amount used, when/how the participant started smoking, and time since last cigarette were asked. Participants were also asked if they chewed tobacco, smoked tobacco in a pipe, or smoked "tailor made" and/or "roll your own: cigarettes.

Where required, research workers from the local community were able to provide a personal assessment of study participants' smoking status[41], a feasible indicator given sharing tobacco is an integral component of the collective social fabric of community life[42].

BCO was measured at interview using a hand-held Bedfont piCO+ Smokerlyzer (Bedfont Scientific, UK, http://www.bedfont.com). Participants were requested to inhale and hold their breath for 15 seconds before exhaling into the analyzer. A BCO cutoff of ≥7 ppm was used as recommended by the manufacturer. The BCO analyzers used in the study were calibrated by the manufacturer in May 2008 before the survey commenced and recalibrated by DM, according to the manufacturer's specifications, in November 2008. In trials of survey procedures, the acceptability of using a portable BCO analyzer with this population proved to be high. During the study, it was the experience of DM, JR, and AC that using the BCO analyser attracted participants into the study. The immediate return of BCO results provided an opportunity for participants to actively engage in discussion about tobacco smoking and have direct benefit from participating.

Data analysis and approvals

Data were included in the analysis if: (i) self-reported smokers reported smoking tobacco within the preceding 24 hours; or (ii) self-reported nonsmokers reported never smoking tobacco or not smoking tobacco for ≥6 months[43]. Given the short half-life of BCO, data from self-reported occasional tobacco smokers who reported last smoking tobacco greater than 24 hours previously were not included in the analysis.

Self-reported smoking and BCO level were analyzed descriptively using sensitivity and specificity percentages and a Receiver Operating Characteristics (ROC) analysis.

Sensitivity was defined as the proportion of all self-reported smokers for whom there was a positive BCO test, i.e., a BCO level at or above cutoff (≥7 ppm). Specificity was the proportion of nonsmokers for whom there was a negative BCO test, i.e., a BCO level below cutoff point (<7 ppm). Since a test should ideally have high sensitivity and high specificity, the average of sensitivity plus specificity was calculated for different cutoff points to find the highest level.

Ethics approval for the study was provided by the Human Research Ethics Committee of James Cook University (approval number H 3072) and the NT Department of Health and Families and Menzies School of Health Research (approval number 0707).

Results

Among the 400 people interviewed, 300 (75%) reported they smoked tobacco, and 100 (25%) reported they did not. Four of the 400 interviewed explicitly refused a BCO test, and 19 were in such poor health that a BCO test would have been unnecessarily intrusive. BCO was not tested in a further 57 people interviewed primarily because they had no time to take the BCO test (n = 40) or because a BCO analyzer was not available at the time of interview (n = 17). The remaining 320 people who provided both a BCO test and information about their tobacco use included 260 who self-reported they smoked tobacco and 60 people who self-reported they did not smoke tobacco. Eleven of the 260 were occasional tobacco smokers and reported they had not smoked within the preceding 24 hours. In accordance with inclusion criteria, these 11 occasional smokers were not included in the analysis. Therefore, BCO tests for 249 self-reported smokers and 60 self-reported nonsmokers were analyzed. The proportions of self-reported smokers (81% = 249/309) and nonsmokers (19% = 60/309) in this subsample were similar to proportions of self-reported smokers (75%) and nonsmokers (25%) in the sample overall ($|z| = 1.90$, $P = 0.057$).

Sensitivity and Specificity

Of the 249 self-reported smokers, 10 had BCO below the cutoff of ≥7 ppm (96.0% sensitivity), and of the 60 self-reported nonsmokers, four had BCO ≥7 ppm (93.3% specificity) (Table 1).

Of the four self-reported nonsmokers with BCO ≥7 ppm, three were males, two of whom stated they did not smoke tobacco but smoked cannabis (BCO 8 ppm and 33 ppm) (Figure 1). The third male (BCO 14 ppm) provided no comment, but local research workers later suggested that he smoked cannabis (Figure 1). One self-reported female nonsmoker with BCO ≥7 ppm (BCO 9 ppm, Figure 1) provided no further detail at interview, and local research workers were not present at interview to assist in clarifying the discrepancy.

Nine of the 10 self-reported smokers with BCO level <7 ppm provided information about time since last cigarette. Five reported their last cigarette was smoked approximately 8-12 hours prior (including three whose last cigarette was smoked the previous evening). Two had smoked approximately six hours prior, and two had their last cigarette within two hours before testing (data not shown).

Table 2 shows changes in sensitivity and specificity at different BCO cut-offs. The highest average for the combined sensitivity and specificity (96%) occurs at BCO cutoffs of ≥5 ppm and ≥6 ppm (Table 2).

Alternative Cut-off Level

If a cutoff level of ≥5 ppm had been used in the study, the number of false negative tests in self-reported smokers would have been reduced by nine from 10 to 1, a reduction in the proportion of negative tests from 15% to 2%. Using a BCO cutoff of ≥ 5 ppm would substantially increase the sensitivity in the study from 96.0% to 99.6% with no change in specificity (93.3%) (Table 2). However excluding data for the two male cannabis users who said they did not smoke tobacco from analysis increased specificity to 96.6% (data not shown).

An ROC analysis was performed to assess the diagnostic accuracy of BCO across the range of possible cutoff values (Figure 2). The significant contribution to the area under the curve (AUC = 0.972, $P < 0.001$) at a BCO cutoff of ≥5 ppm indicates the considerable power the BCO marker holds to discriminate between smokers and nonsmokers in this population. With the data for the two male self-reported cannabis smokers excluded from the ROC analysis, the area under the curve at a BCO cutoff of ≥5 ppm increased marginally to AUC = 0.989. For prevalence estimates in the sample, a cutoff level of ≥7 ppm would have estimated a prevalence of 79% of smokers. Using a cutoff level of ≥5 ppm would have estimated a prevalence of 82% of smokers. With data for the two male cannabis smokers excluded, using a cutoff level of ≥5 ppm would have estimated tobacco smoking prevalence of 81%, the proportion of self-reported smokers in the sample of 400 people interviewed in the study overall.

Discussion

These findings indicate that BCO can be effectively used to validate self-reported smoking in remote Australian Indigenous communities. The strong agreement between self-reported smoking and BCO indicates that self-reported smoking can be considered a reliable measure in this population.

Table 1 Breath carbon monoxide (BCO) and self-reported smoking status

BCO level (p.p.m.)	Self-reported non-smokers (n)	Self-reported smokers (n) in BCO range				Total (n)
		0-5 p.p.m.	6-10 p.p.m.	11-15 p.p.m.	>15 p.p.m.	
1	22					22
2	20	1				21
3	11					11
4	3					3
5		2				2
6			7			7
≥7	4		42	66	131	243
Total						309

Limitations of the study include that the sample was not randomly selected and so results cannot be generalized. However, participants were recruited to reflect each community's age and gender characteristics. Although BCO was not tested in all participants, the gender composition and proportions of self-reported smokers among those who provided a BCO test were similar to the sample overall. Confidence in the results is further reinforced by the high level of agreement between BCO and self-report, by the similarly high smoking rates found in other studies in the region, and because community members themselves informed researchers that results reflected their own family and community experience.

The community-based survey method recorded self-reported smoking status and immediately returned BCO test results to study participants. This allowed discrepancies between self-report and BCO to be investigated at the time of interview with further questions about smoking history or pattern of use, which assisted in refining the data.

Ten (4%) self-reported smokers had BCO below the ≥7 ppm cutoff. In nine of these, the self-reported time since last cigarette was between 2 and 12 hours prior to BCO test. Three of these nine had not smoked since the previous evening. Given that BCO has a half-life of between 3 and 4 hours and can decline by 2.1 to 7.5 ppm per hour, depending on the initial BCO level[44],

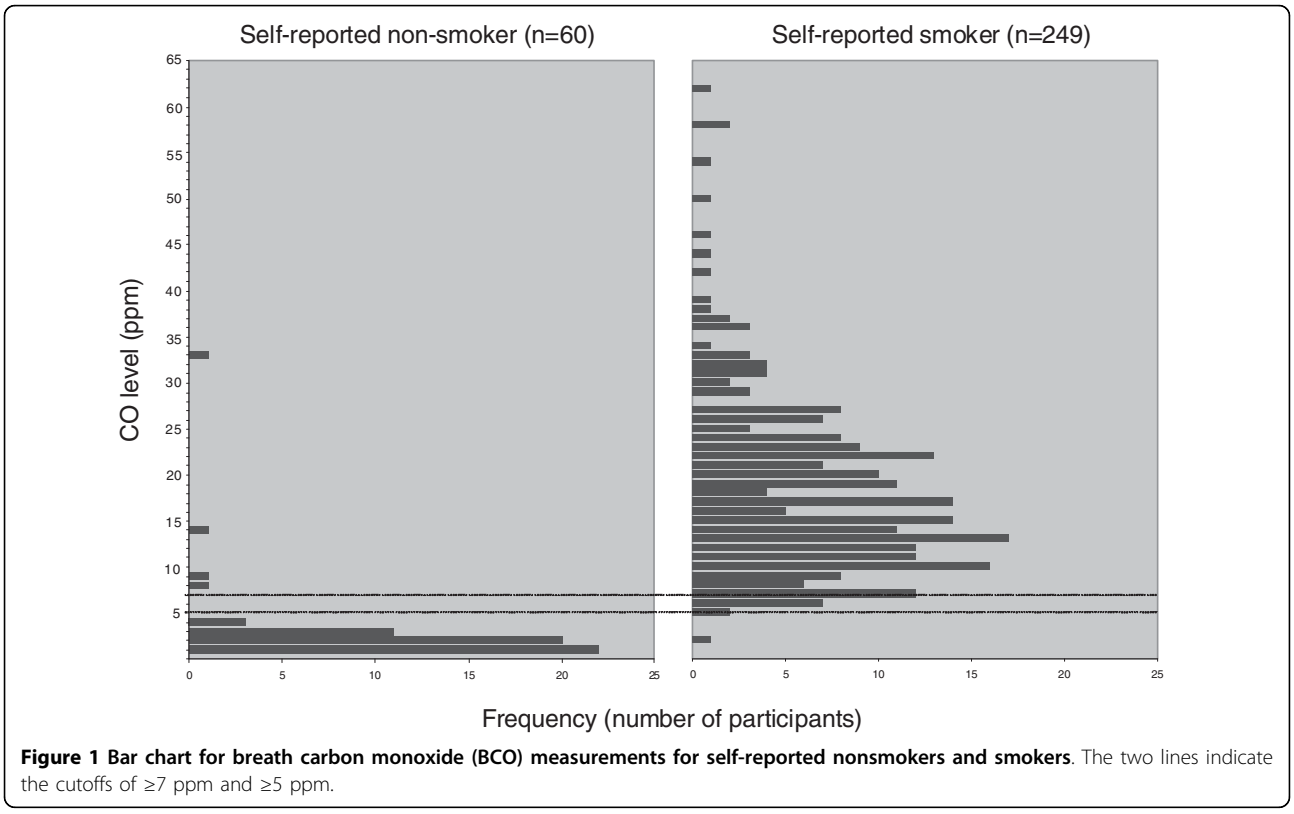

Figure 1 Bar chart for breath carbon monoxide (BCO) measurements for self-reported nonsmokers and smokers. The two lines indicate the cutoffs of ≥7 ppm and ≥5 ppm.

Table 2 Sensitivity and specificity of various breath carbon monoxide (BCO) cutoff levels

CO cut-off ≥ (p.p.m.)	Sensitivity	Specificity	(Sensitivity + specificity)/2
1	1.000	0.000	0.50
2	1.000	0.367	0.68
3	0.996	0.700	0.85
4	0.996	0.883	0.94
5	0.996	0.933	**0.96**
6	0.988	0.933	**0.96**
7	0.960	0.933	0.95
8	0.912	0.933	0.92
9	0.888	0.950	0.92
10	0.855	0.967	0.91

there was sufficient time for BCO to decline below the cutoff. Smokers consistently reported periods of heavy and light smoking with a greater amount of tobacco smoked in the first few days after fortnightly paydays. Similar to smoking patterns documented in other Indigenous communities[42], the majority of participants reported regularly running out and frequently requesting tobacco from family and friends. This provides a plausible explanation for self-reported tobacco smokers who only smoke occasionally and/or have low BCO. Although those who smoke few cigarettes per day can also have normal BCO[21,23,44], lapsed time since last cigarette, independent of the number of cigarettes smoked, accounted for most self-reported smokers with low BCO in this study.

The study also documented four (7%) self-reported nonsmokers with BCO ≥7 ppm. While such discrepancies may allude to false self-report or exposure to secondhand smoke, two of these four results could be accounted for by cannabis use. It is possible that exposure to secondhand smoke contributed to the small number of false positives in this study, however cannabis use in this population is likely to be an important factor. Studies of cannabis use in similar communities in the same region indicate that most cannabis users (94%) blend cannabis with tobacco and smoke the mixture in handmade "bucket bongs," with tobacco smokers about 19 times more likely than nonsmokers to also smoke cannabis[45]. Given that up to two-thirds of males and half of females regularly use cannabis in the region's communities[45,46], cannabis use should be considered where self-reported nonsmokers show high BCO in further self-reported smoking validation studies. The present study did not systematically collect data about cannabis use at interview. A study investigating both

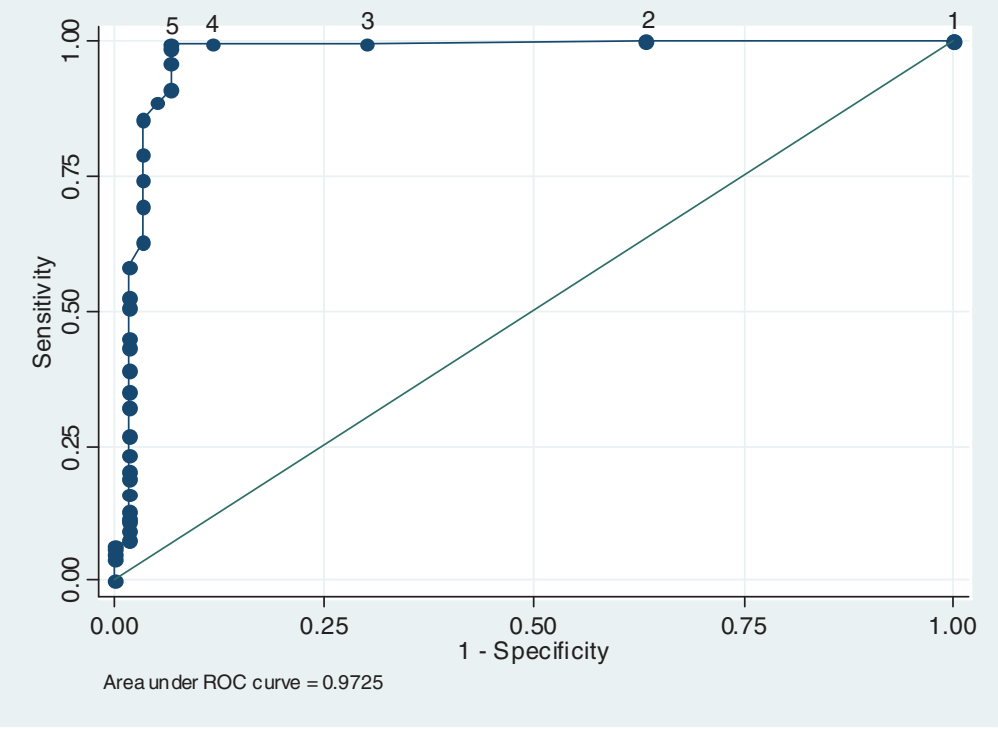

Figure 2 For receiver operating characteristic (ROC) analysis, using data for all participants, 1-specificity (x-axis) was plotted against sensitivity at breath carbon monoxide (BCO) cutoff levels from 1 ppm to 10 ppm. The numbers placed along the ROC curve indicate BCO cutoff levels.

tobacco and cannabis smoking requires a different approach, including suitable protocols designed to minimize the ethical and legal risks of studying illegal behaviors in these disadvantaged and disempowered populations in Australia[45].

Only a few studies in Indigenous Australian populations have used biomarkers to verify self-reported smoking. A community-based study in an urban population recorded 10% of self-reported nonsmokers with BCO above cutoff of 9 ppm[26], while a clinic-based study in a remote population tested BCO but did not analyze discrepancies[25]. Two clinic-based studies using urine cotinine, one remote and one urban, both found higher discrepancies. The remote study found 15% of self-reported nonsmokers produced levels above cutoff (539 nmom/l)[7], while the urban study found 17% of self-reported nonsmoking pregnant women produced levels above cutoff (250 ng/ml)[14]. In the study reported here, 7% of self-reported nonsmokers had BCO above cutoff (≥7 ppm). Caution is, however, required before making direct comparison between these studies given the different population groups, recruitment methods, sample size, biomarkers, and study context.

A range of BCO cutoff levels has been used to validate self-reported smoking in different population groups around the world. Cutoffs as high as 10 ppm have been used[20,47,48]. Others have used 9 ppm[22,26,37,44]; 8 ppm[19]; 7 ppm[28]; 6.5 ppm[17]; or 6 ppm[21]. Several studies recommend cutoffs as low as 2 to 3 ppm [29,31,36]. However, self-reported smoking status and BCO level can vary between ethnic groups in the same location[23]. This suggests possible cultural or communication differences in responses to questions about smoking, a challenge well-known in remote Aboriginal communities[7,39]. Different sociocultural patterns of smoking may mean different BCO cutoffs are required in different populations. In this study population, reducing the BCO cutoff from ≥7 ppm to ≥5 ppm would increase the self-reported smokers verified from 96.0% to 99.6%, while self-reported nonsmokers verified would remain unchanged at 93.3%. With better information in future studies about those who smoke cannabis and not tobacco in these communities, the proportion of self-reported nonsmokers of tobacco verified could be as high as 96.6%.

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Authors' contributions

DM participated in collection, analysis, and interpretation of data, and drafted and edited the manuscript. KC made substantial contributions to the conception and design of the study, analyzed and interpreted data, and revised the manuscript. JR participated in collection of data and revised the manuscript. RI participated in the conception and design of the study and revised the manuscript. SE participated in the conception and design of the study and revised the manuscript. AC led the conception and design of the study, participated in data collection, led the statistical analysis of results, and critically revised all sections for intellectual content. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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