

**USING BREATH CARBON MONOXIDE TO VALIDATE 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 cut-off level for validating self-reported tobacco smoking in Indigenous Australians in Arnhem Land, Northern Territory (NT).

### **Methods:**

A total of 400 participants ( $\geq 16$  years) were interviewed about tobacco use in three communities with a combined Indigenous population of 1104 males and 1215 females ( $\geq 16$  years). Participants were opportunistically recruited using quotas to reflect community age and gender balances. Local Indigenous research workers assisted researchers to interview participants and facilitate BCO tests using a portable hand-held analyser.

### **Results:**

Both self-reported smoking and BCO data were available for 320 participants. Of these, 260 (81%) were self-reported smokers and 60 (19%) were self-reported non-smokers. A BCO cut-off of  $\geq 7$  parts per million (p.p.m.) provided good agreement between self-report and BCO (93.8% sensitivity, 90.3% specificity in males; 89.5% sensitivity, 96.6% specificity in females). An alternative cut-off of  $\geq 5$  p.p.m. in the entire sample increased sensitivity from 91.9% to 97.3% without changing specificity (93.3%). Using the BCO analyser in public spaces, coupled with immediate feedback of results encouraged interest in effects of smoking and assisted to recruit study participants.

**Conclusion:**

In these disadvantaged Indigenous populations, where data describing smoking are few, testing for BCO provides a non-invasive and immediate method to validate self-reported smoking. Strong agreement between self-report and BCO indicates self-reported smoking status can be considered a reliable measure in this population. The hand-held BCO analyser warrants further investigation as a health promotion tool in these communities.

## **Introduction**

Despite Australia being a world leader in tobacco control, significant disparities in smoking rates exist between Indigenous and non-Indigenous Australians. Over the past two decades smoking rates have halved in the general community from 35% to 18% with predictions of 14% by 2020[1]. 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]. However smoking rates vary across Indigenous Australian populations. For example, much higher rates of between 59% to 83% 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[3-8].

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]. Around 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 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) analysers are tools used to immediately assess smoking status, 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 analysers and optimum BCO cut-off to distinguish smokers and non-smokers is being investigated in different populations around the world[27-36] with different cut-off levels recommended in different populations dependent on the intended use of 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 cut-off level to validate self-reported smoking in community-based surveys in Indigenous Australian populations.

This paper examines the sensitivity and specificity of the BCO test and the optimal cut-off level to distinguish between smokers and non-smokers in three remote Indigenous populations. It also discusses the utility of the BCO analyser in this setting.

## **Methods**

### Setting

The study was conducted in three Arnhem Land communities with a combined Indigenous population of 3770 including 1104 males and 1215 females aged  $\geq 16$  years. Contemporary life is strongly influenced by traditional social and cultural norms and practices with over 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 17<sup>th</sup> century by Macassan traders from the Indonesian archipelago, and extended with the expansion of the pastoral industry and Christian missions during the early 20<sup>th</sup> century.[40]

### Sampling

Between July 2008 and February 2009, 400 Indigenous people (aged  $\geq 16$ ), 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 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 Smoking

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 started smoking and time since last cigarette were asked. Participants were also asked if they chewed tobacco, smoked tobacco in a pipe, smoked ‘tailor made’ and/or ‘roll your own’ cigarettes. Smokers were defined as those who self-reported regular or occasional smoking. Non-smokers were defined as those who reported never smoking or not smoking for  $\geq 6$  months[42].

Where required, local community research workers 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[43].

### Community Survey: Breath Carbon Monoxide (BCO)

BCO was measured at interview using a hand held Bedfont piCO+ Smokerlyzer (Bedfont Scientific, UK, [www.bedfont.com](http://www.bedfont.com)). Participants were requested to inhale and hold their breath for 15 seconds before exhaling into the analyser. A BCO cut-off of  $\geq 7$  p.p.m. was used as recommended by the manufacturer.

### Data analysis and Approvals

Self-reported smoking and BCO level were analysed 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 cut-off ( $\geq 7$  p.p.m.). Specificity was the proportion of non-smokers for whom there was a negative BCO test, i.e. a BCO level below cut-off point ( $< 7$  p.p.m.). The average of sensitivity plus specificity was calculated for each cut-off point 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

### Community Survey: Self-reported Smoking

Interviews were conducted with 400 participants comprising 206 males (52%) and 194 females (48%). There were 305 self-reported tobacco users comprising 160 males and 145 females. Four female tobacco users reported exclusively chewing tobacco; all four reported they had never smoked. One male reported exclusively chewing tobacco, but 40 years ago had smoked for 12 months. All five tobacco chewers were categorised as non-smokers. Self-reported smokers therefore comprised 75% (n=300) of the sample; 77% (n=159) of males and 73% of females (n=141).

### Community Survey: BCO levels

Of the 400 participants interviewed, four (1%) explicitly refused a BCO test and 19 (5%) were in such poor health that a BCO test would have been unnecessarily intrusive. BCO was not tested in a further 57 participants (14%) primarily because participants stated they had no time (n=40) or because a BCO analyser was not available at the time of interview (n=17).

In all, 320 participants provided both self-reported tobacco use data and BCO test. These included 260 self-reported smokers (81%) and 60 self-reported non-smokers (19%), proportions which were similar to proportions of self-reported smokers (75%) and non-smokers (25%) in the sample overall ( $|z|=1.92$ ,  $P=0.055$ ). The proportions of male smokers (82%=146/177) and female smokers (80%=114/143) among the 320 participants were similar (OR=1.2, 95%CI=0.7-2.1,  $P=0.913$ ).

The average BCO in males was higher (mean BCO=19 p.p.m., SD=10.4 p.p.m.) than in females (mean BCO=16 p.p.m., SD=9.5 p.p.m.), a statistically significant difference ( $t=2.6$ ,  $P=0.011$ ). Because of these gender differences the BCO results and self-reported smoking for males and females are analysed and summarized separately.

#### Sensitivity and Specificity:

In males, of the 146 self-reported smokers, nine had BCO below the cut-off of  $\geq 7$  p.p.m (93.8% sensitivity) and of the 31 self-reported non-smokers, three had BCO  $\geq 7$  p.p.m (90.3% specificity) (Table 1a). In females, of the 114 self-reported smokers, 12 had BCO  $< 7$  p.p.m (89.5% sensitivity) and of the 29 self-reported non-smokers, one had a BCO  $\geq 7$  p.p.m (96.6% specificity) (Table 1b).

Of the three self-reported male non-smokers with BCO  $\geq 7$  p.p.m., two stated they did not smoke tobacco but smoked cannabis (BCO 8 p.p.m. and 33 p.p.m.). The third (BCO 14 p.p.m.) provided no comment but local research workers later confirmed he smoked cannabis (Figure 1a). The one self-reported female non-smoker with BCO  $\geq 7$  p.p.m. (BCO 9 p.p.m., Figure 1b) provided no further detail at interview and local research workers were not present at interview to assist to clarify the discrepancy.

Eight of the nine self-reported male smokers with BCO level  $< 7$  p.p.m. provided information about time since last cigarette. Three reported their last cigarette was smoked a day or more prior to BCO test. Four reported their last cigarette was smoked

approximately 8-12 hours prior and the eighth two hours prior to testing. Eleven of the 12 self-reported female smokers with BCO level  $<7$  p.p.m., provided information about time since last cigarette. Eight reported their last cigarette was smoked at least a day prior to testing, two approximately six hours prior and the eleventh two hours prior to testing (data not shown).

Tables 2a and 2b show changes in sensitivity and specificity at different BCO cut-offs in males and females. For males the highest average for the combined sensitivity and specificity (94%) occurred at a BCO cut-off of  $\geq 5$  p.p.m. (Table 2a), while for females the highest average (97%) was at  $\geq 4$  p.p.m. (Table 2b). When plotted, the differences between males and females are emphasised (Figures 2a and 2b).

#### Alternative Cut-off Level:

If a cut-off level of  $\geq 5$  p.p.m. had been used in the study overall, the number of 'false negative' tests in self-reported smokers would have been reduced by 14 from 21 to 7, a reduction in the proportion of negative tests from 27% to 11%. Using a BCO cut-off of  $\geq 5$  p.p.m. would substantially increase the sensitivity in the study from 91.9% to 97.3% with no change in specificity (93.3%).

A receiver-operating characteristic (ROC) analysis using information for all participants was performed to assess the diagnostic accuracy of BCO across the range of possible cut-off values (Figure 3). The significant contribution to the area under the curve (AUC=0.965,  $P<0.001$ ) at a BCO cut-off of  $\geq 5$  p.p.m. indicates the considerable power

the BCO marker holds to discriminate between smokers and non-smokers in this population. For prevalence estimates in the sample, a cut-off level of  $\geq 7$  p.p.m. would have estimated a prevalence of 76% of smokers. Using a cut-off level of  $\geq 5$  p.p.m. would have estimated a prevalence of 80% of smokers, a level remarkably close to the 81% of self-reported smokers.

## **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.

Limitations of the study include that the sample was not randomly selected and so results cannot be generalised. 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.

Discrepancies between self-report and BCO level can be accounted for:

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 to refine the data.

Twenty-one (8%) self-reported smokers had BCO below the  $\geq 7$  p.p.m cut-off. In 19 of these 21, the self-reported time since last cigarette was between two hours and one week prior to BCO test. Given that BCO has a half life of between 3 to 4 hours and can decline by 2.1 to 7.5 p.p.m. per hour, depending on the initial BCO level[44], there was sufficient time for BCO to decline below the cut-off. 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[43], the majority of participants reported regularly running out and frequently requesting tobacco from family and friends. This provides a plausible explanation for self-reported smokers with 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 number of cigarettes smoked, accounted for most self-reported smokers with low BCO in this study.

The study also documented four (7%) self-reported non-smokers with BCO  $\geq 7$  p.p.m.. While such discrepancies may allude to false self-report or exposure to second hand smoke, three of these four results could be accounted for by cannabis use. The fourth was not asked, nor volunteered information about cannabis. 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 non-smokers show high BCO in further smoking studies.

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 non-smokers with BCO above cut-off of 9 p.p.m.[26], while a clinic-based study in a remote population tested BCO but did not analyse 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 non-smokers produced levels above cut-off (539nmom/l)[7] while the urban study found 17% of self-reported non-smoking pregnant women produced levels above cut-off (250 ng/ml)[14]. In the study reported here 7% of self-reported non-smokers had BCO above cut-off ( $\geq$  7 p.p.m). Caution is however required before making direct comparison between these studies given the different population groups, recruitment methods, sample size, biomarkers and study context.

#### Optimal BCO cut-off levels:

A range of BCO cut-off levels have been used to validate self-reported smoking in different population groups around the world. Cut-offs as high as 10 p.p.m. have been used[20, 47, 48]. Others have used 9 p.p.m[22, 26, 37, 44]; 8 p.p.m.[19]; 7 p.p.m.[28] 6.5 p.p.m.[17]; 6 p.p.m.[21]. Several studies recommend cut-offs as low as 2-3 p.p.m.[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 cut-offs are required in different populations. In this study population

reducing the BCO cut-off from  $\geq 7$  p.p.m. to  $\geq 5$  p.p.m. would increase the self-reported smokers verified from 91.9% to 97.3% while self-reported non-smokers verified would remain unchanged at 93.3%.

Usefulness and acceptability of BCO test:

The acceptability of using a portable BCO analyzer with this population proved to be high. It was the experience of DM, JR and AC that using the BCO analyser attracted participants into the study. Many community members requested to participate after observing a family member or friend undertake a BCO test. The immediate return of BCO results provided an opportunity for participants to actively engage and have direct benefit from participating. Most participants discussed their BCO result and smoking further with researchers. The utility of the BCO analyser changed through the study from initially being a tool to objectively validate self-reported tobacco smoking into a health promotion tool which allowed people to consider impacts of their own smoking. Further research is needed to assess the full potential of a portable hand-held BCO analyser as both a validation and health promotion tool for smoking cessation initiatives in remote Australian Indigenous communities and other populations.

## **List of Abbreviations**

BCO Breath Carbon Monoxide  
p.p.m. parts per million

## **Competing Interests**

The authors declare they have no competing interests.

## **Authors Contributions**

DM participated in collection, analysis and interpretation of data, drafted and edited the manuscript. KC made substantial contribution to the conception and design of the study, analysed and interpreted data, 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.

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**Table 1(a) Breath carbon monoxide (BCO) and self-reported smoking status for males**

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	6					6
2	12	<b>1</b>				13
3	7	<b>1</b>				8
4	3					3
5		<b>1</b>				1
6			<b>6</b>			6
≥7	<b>3</b>		20	37	80	140
<b>Total</b>						<b>177</b>

**Table 1(b) Breath carbon monoxide (BCO) and self-reported smoking status for females**

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	16					16
2	8	<b>3</b>				11
3	4	<b>1</b>				5
4		<b>1</b>				1
5		<b>4</b>				4
6		<b>3</b>				3
$\geq 7$	<b>1</b>		22	29	51	103
<b>Total</b>						<b>143</b>

**Table 2(a) Sensitivity and specificity of various breath carbon monoxide (BCO) cut-off levels for males**

BCO cut-off (p.p.m.)	Sensitivity	Specificity	(Sensitivity + specificity)/2
1	1.000	0.000	0.50
2	1.000	0.194	0.60
3	0.993	0.581	0.79
4	0.986	0.806	0.90
5	0.986	0.903	<b><u>0.94</u></b>
6	0.980	0.903	<b><u>0.94</u></b>
7	0.938	0.903	0.92
8	0.925	0.903	0.91
9	0.904	0.936	0.92
10	0.877	0.936	0.91

**Table 2(b) Sensitivity and specificity of various breath carbon monoxide (BCO) cut-off levels for females**

BCO cut-off (p.p.m.)	Sensitivity	Specificity	(Sensitivity + specificity)/2
1	1.000	0.000	0.50
2	1.000	0.520	0.76
3	0.974	0.828	0.90
4	0.965	0.966	<b><u>0.97</u></b>
5	0.956	0.966	0.96
6	0.921	0.966	0.94
7	0.895	0.966	0.93
8	0.807	0.966	0.89
9	0.781	0.966	0.87
10	0.746	1.000	0.87

**List of Figures provided as separate files:**

Figure 1 (a) Bar chart for breath carbon monoxide (BCO) measurements for self reported non-smokers and smokers.

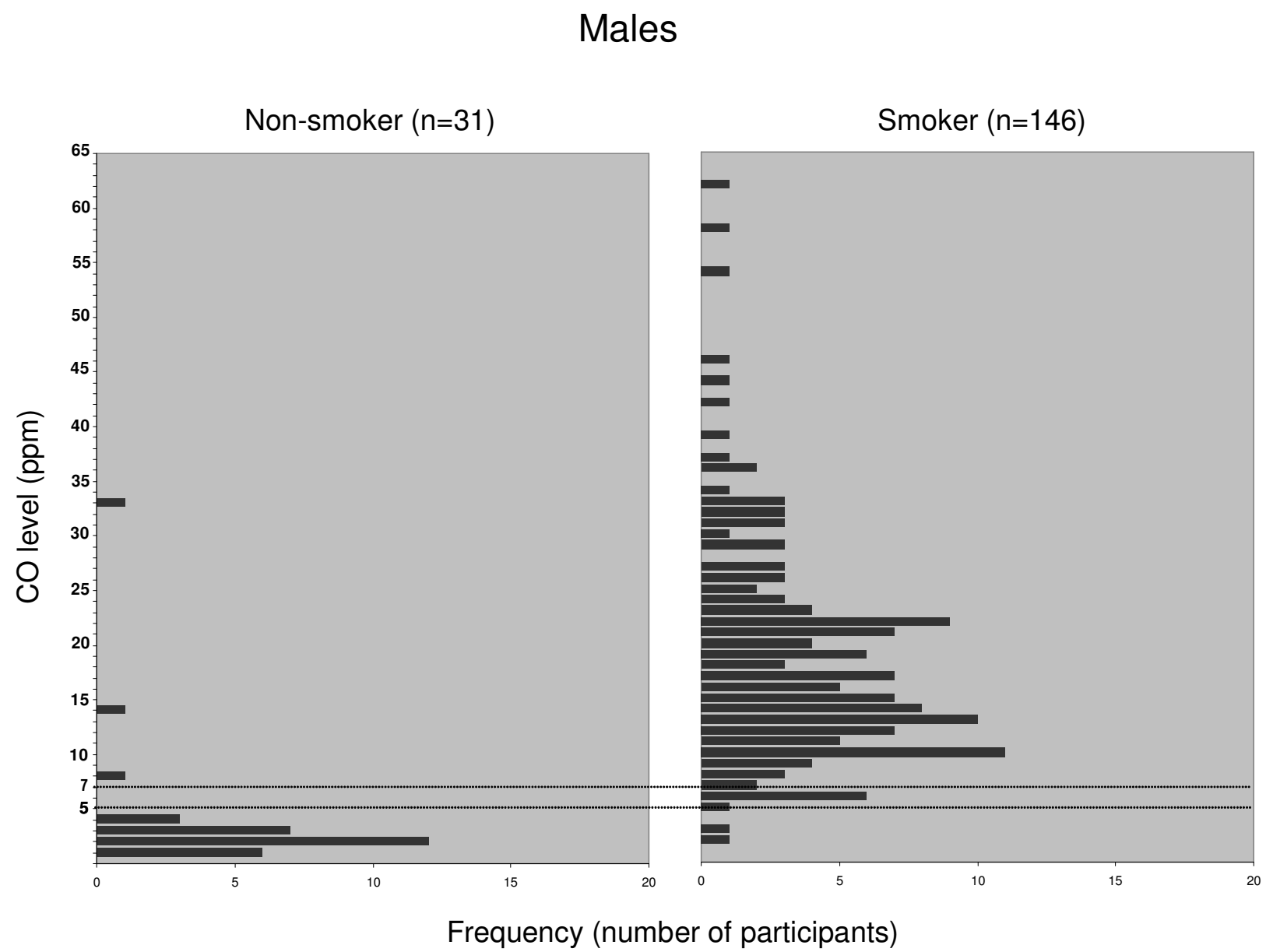
Figure 1(b) Bar chart for breath carbon monoxide (BCO) measurement for self reported non-smokers and smokers.

Figure 2(a) Sensitivity and specificity at BCO cut-off levels from 1 p.p.m. to 10 p.p.m.

Figure 2(b) Sensitivity and specificity BCO cut-off levels from 1 p.p.m. to 10 p.p.m.

Figure 3 Receiver operating characteristic (ROC) analysis, using data for all participants.

**Figure 1 (a)** Bar chart for breath carbon monoxide (BCO) measurements for self reported non-smokers and smokers. The two lines indicate the cut-offs of  $\geq 7$  p.p.m. and  $\geq 5$  p.p.m.



**Figure 1(b)** Bar chart for breath carbon monoxide (BCO) measurement for self reported non-smokers and smokers. The two lines indicate the cut-offs of  $\geq 7$  p.p.m. and  $\geq 5$  p.p.m.

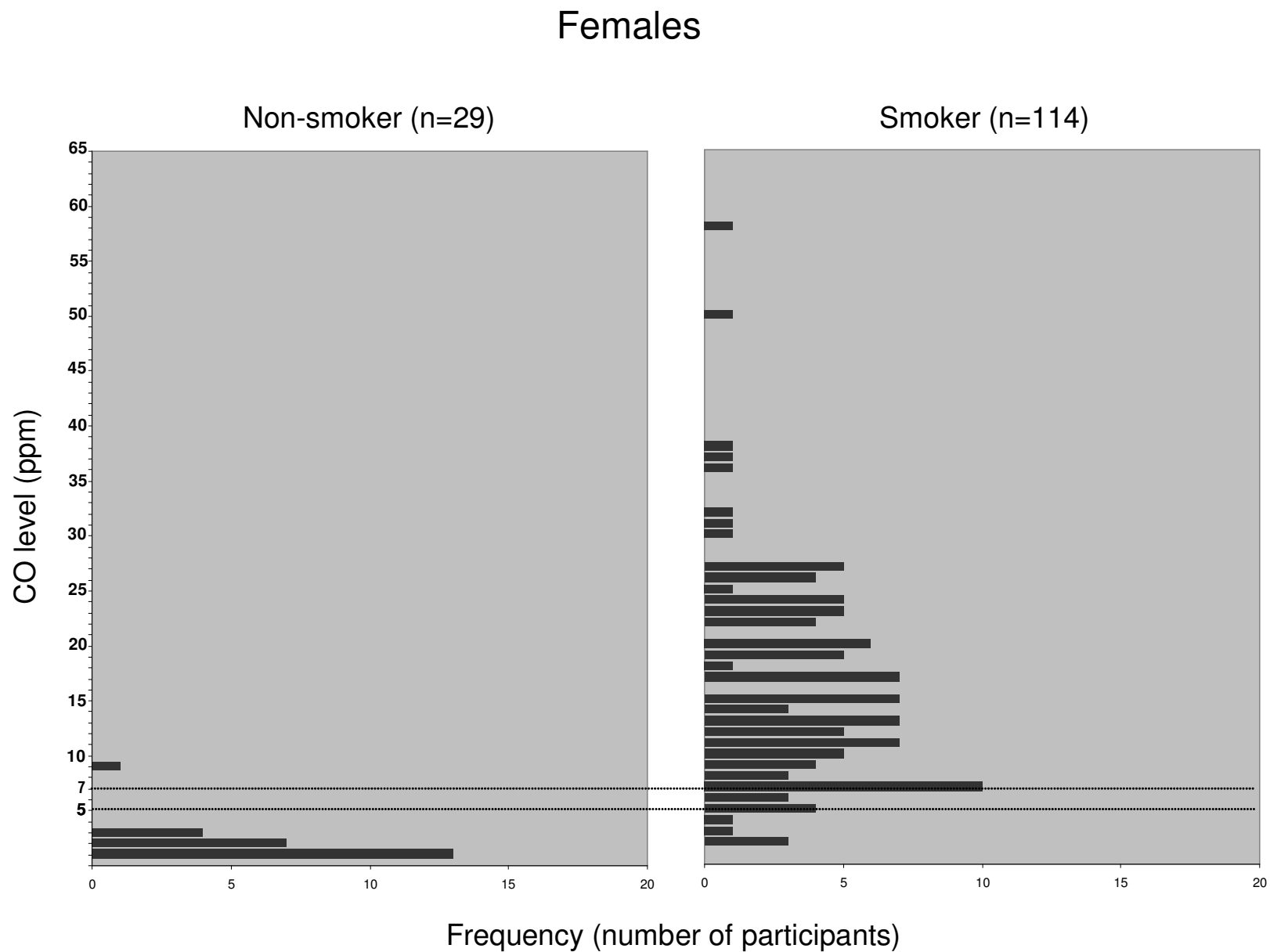


Figure 2(a) Sensitivity and specificity at BCO cut-off levels from 1 p.p.m. to 10 p.p.m.

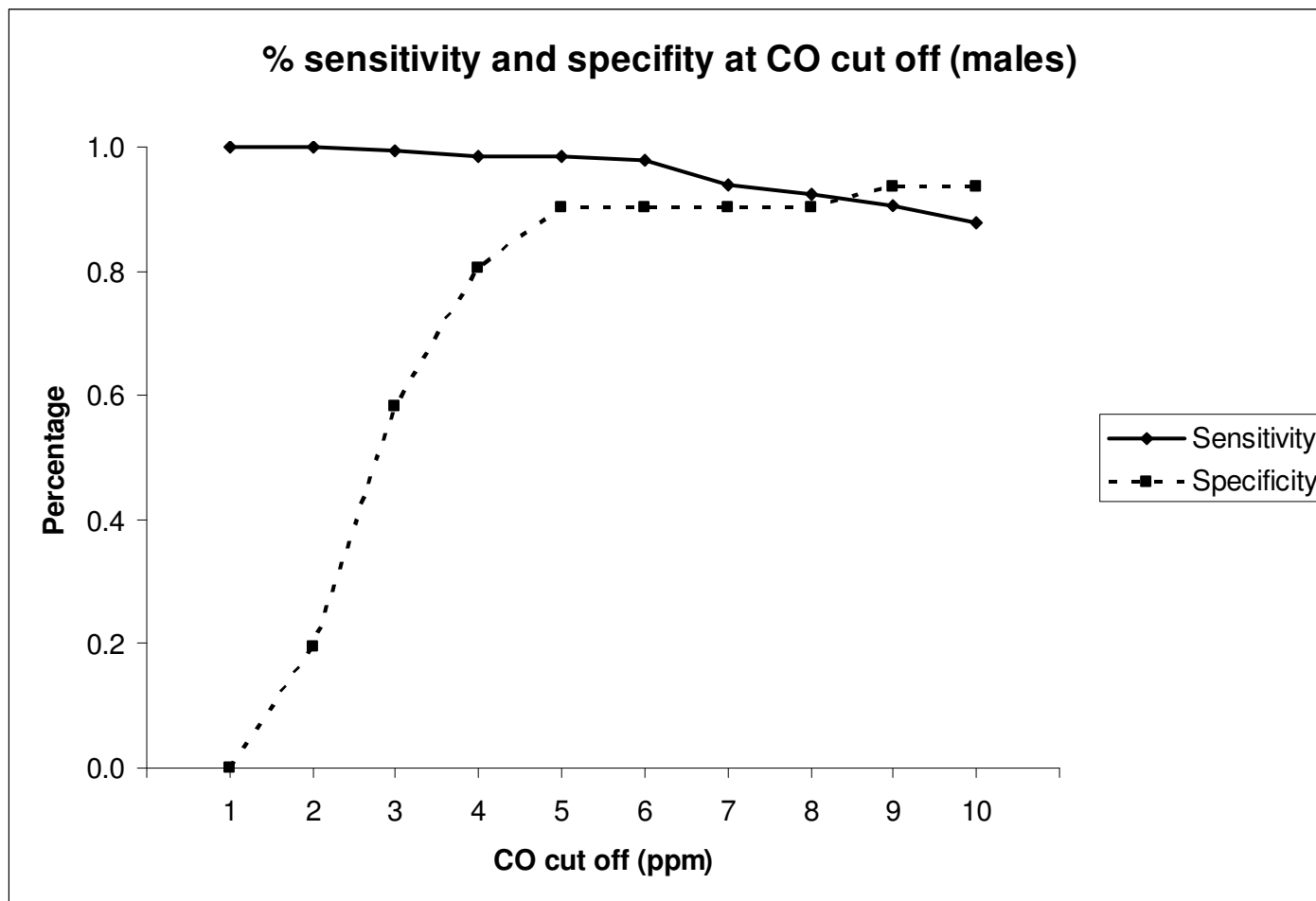
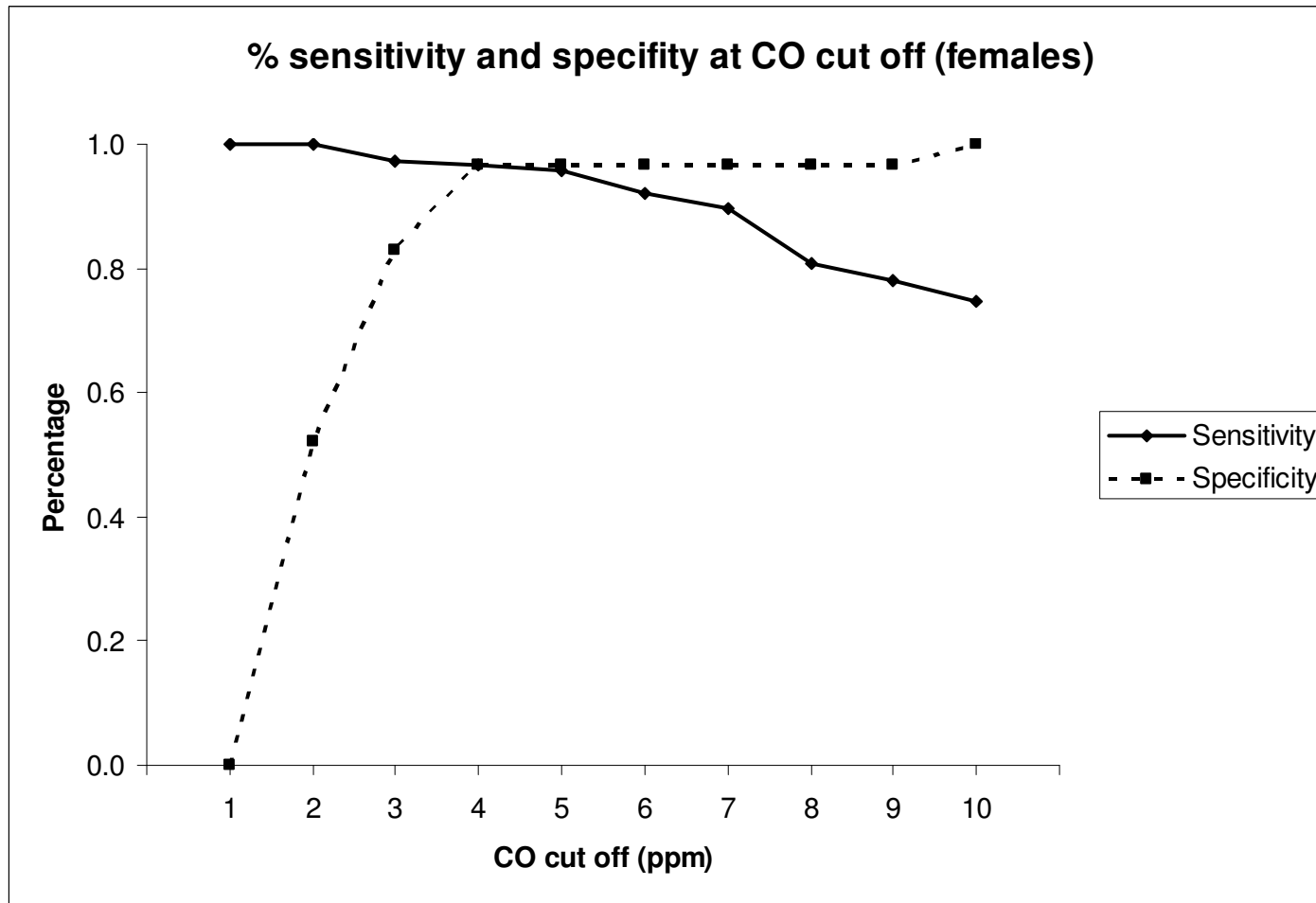


Figure 2(b) Sensitivity and specificity BCO cut-off levels from 1 p.p.m. to 10 p.p.m.



**Figure 3** Receiver operating characteristic (ROC) analysis, using data for all participants. 1-specificity (x-axis) was plotted against sensitivity at breath carbon monoxide (BCO) cut-off levels from 1 p.p.m. to 10 p.p.m. The numbers placed along the ROC curve indicate BCO cut-off levels.

