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CABIN AIR QUALITY: COTININE AS A BIOMARKER OF ENVIRONMENTAL TOBACCO SMOKE IN COMMERCIAL AIRCRAFT

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The use of cotinine as a biomarker for evaluating air quality with respect to environmental tobacco smoke in commercial aircraft has been studied by determining the variation in concentration of nicotine and other environmental tobacco smoke pollutants in both smoking and nonsmoking cabin sections. Four never-smoker volunteers were exposed during commercial passenger flights and atmospheric samples were collected to determine exposure of the personnel to nicotine for at least the 24 hour period before and 48 hour period after the flight. Total urine samples were obtained from the personnel collecting the atmospheric samples for the time period extending from 24 hours before the flight to 48 hours after the flight. Exposure in airport terminals can be as significant as exposure for persons sitting a few rows in front of the smoking section during a flight. Urine cotinine concentrations were correllated with exposure to nicotine but not with exposure to many other constituents of environmental tobacco smoke in a series of DC-10 flights.

Introduction

In recent years there has been an increased interest in determining the concentrations of ETS in commercial aircraft passenger cabins in order to quantify the concentrations of pollutants associated with ETS which may be present, determine the factors which control the concentrations of ETS present in nonsmoking sections of passenger cabins, and develop models for predicting personal exposure in commercial aircraft. A National Academy of Sciences report (1) recommended banning smoking on all commercial flights for the following reasons: minimization of irritation, reduction of health risks and fire hazards, and to bring levels of pollutants in cabin air in line with those in other indoor environments. In April 1988, the U.S. Congress enacted a temporary law banning smoking on all flights of two hours or less. In February 1990, a new law went into effect which banned smoking on domestic U.S. airline flights. Similar legislation is in effect in Canada. Most flights in other countries do not presently ban smoking.

Several studies have determined the concentration of ETS components present in commercial aircraft cabins. Data have been reported on the concentrations of nicotine present in the cabin environment for a number of commercial aircraft flights (2-6). The exposure of airline flight attendants (4,7) and passengers (4) to environmental tobacco smoke has been estimated from measurements of nicotine and cotinine in urine. Oldaker et. al (2) have reported the determination of the concentrations of nicotine, RSP and UV-PM on several long commercial flights using a portable air sampling system. A similar sampling system was used to determine the concentrations of nicotine, CO and RSP at four locations in the passenger cabin of flights on MD-80 aircraft (5). The latter two studies are the only studies reported to date which have attempted to correlate the concentrations of nicotine in the passenger cabin of commercial aircraft with the concentrations of other constituents of environmental tobacco smoke. Most of the studies have used nicotine as the tracer to quantify exposure. However, exposure calculations based only on nicotine will underestimate total exposure to ETS since nicotine is removed from indoor environments at rates faster than other species associated with ETS (8,9).

We have conducted a study (10) to measure a variety of compounds associated with ETS as well as several non-unique species (such as RSP and CO) in both smoking and nonsmoking sections of aircraft cabins. The spectrum of species and aircraft sampled provided a data base for the development of models for the prediction of ETS concentrations in aircraft cabins under a variety of conditions. As part of that study, the concentrations of cotinine in the urine of passengers with known exposure to nicotine from environmental tobacco smoke before, during and after commercial flights was determined. This paper presents the results obtained from a series of DC-10 flights.

Methods

Sampling Equipment and Analysis Methods

Data on the aircraft were collected by four volunteers using Briefcase Automated Sampling Systems (BASS) (11). Each BASS contained various components designed to sample for specific compounds associated with ETS and other atmospheric pollutants and variables. Compounds measured during a flight included gas and particulate phase nicotine, 3-ethenylpyridine, fine (>2.5μm) particulate matter, UV-PM (2), NO_x and CO. The concentrations of gas and particulate phase nicotine were determined using two mini-annular denuder sections coated with benzenesulfonic acid (BSA) for collection of gas phase nicotine and 3-ethenylpyridine followed by a 1 micron Teflon

filter (Zefluor, Gelman Sciences) for collection and determination of nicotine (12). Following the Teflon filter was a BSA saturated filter for the collection of any nicotine lost from particles during sampling (12). Air was drawn through the denuder system at a rate of 2 slpm. Details on the collection device used to measure the other chemical species have been given (10,11). The concentrations of nicotine to which the four volunteers were exposed in airports prior to and after each flight were determined using a filter pack with a 1 micron Teflon filter (Zefluor, Gelman Sciences) and a BSA saturated filter sampling at 4 slpm for the collection of particulate and gas phase nicotine (12). The concentrations of nicotine present in the environment other than in the airport terminals and during the flight to which the volunteers were exposed was determined using a BSA saturated filter in a passive monitor of the design described by Hammond et al. (13).

A measured fraction of each urine void was collected by each of the four volunteers for the 24 hour period prior to and 48 hour period following each flight. Aliquots of the various samples were combined to give three composite 24 hour samples. After collection the individual urine samples were frozen and kept frozen at -80°C until combined to the 24 hour samples and analyzed.

Annular denuder and filter pack samples were extracted with water and analyzed by ion chromatography for nicotine and 3-ethenylpyridine (14) with the exception of the Teflon filter. The Teflon filter was extracted with methanol, with half of the extract analyzed for UV absorbance using a spectrophotometer to determine UV-PM (15), and the other half was analyzed for nicotine by ion chromatography (16). The concentrations of nicotine collected by the passive samplers was determined by gas chromatography using an NPD detector (12). Cotinine in the collected urine samples was determined by gas chromatography using an NPD detector and internal standard as previously described (14).

Sampling Protocol

Four different volunteer non-smokers participated in four DC-10 flights. Each subject carried a BASS and was seated in the rear passenger cabin which contained the economy class smoking section at the back of the aircraft. The location in the passenger cabin of the volunteers during each flight is given in Table I. Sampling was begun after takeoff when the no-smoking sign was turned off. Sampling was concluded when the no-smoking sign was turned on prior to landing. Flights 1 and 3 and flights 2 and 4 were the same origination and destination, however, a different DC-10 aircraft was flown for each flight. The four volunteers wore the personal passive sampler for a 24 hour period prior to the flight when not in an airport and were at the location of the filter pack sampling system when in an airport. After the flight, the volunteers were again in the area of the filter pack sampling system when in the airport and wore a passive sampler for the 48 hour period after leaving the airport. All volunteers stayed in smoke free residences and avoided any locations where smoking was present before and after each flight.

Results and Discussion

The concentrations of nicotine and the time duration of exposure for the four volunteers for the periods prior to, during, and after each of the four DC-10 flights are given in Table I. The concentrations given are for total nicotine determined using the annular denuder or filter pack sampling system, or of gaseous nicotine determined using the passive sampler. In all cases where both gas and particulate phase nicotine were determined, <95% of

the nicotine was in the gas phase.

The concentrations of nicotine and other selected environmental tobacco smoke constituents as a function of seat location in a flight with a high and moderate concentration of environmental tobacco smoke are given in Figure 1. Complete data for the four flights are available (10,17). The rate of penetration of environmental tobacco smoke constituents from the smoking section into the nonsmoking section follows a first order mechanism (10). The rate of penetration was the same for the various DC-10 aircraft flown in this study. The expected rate of decrease in the concentration of various constituents with distance into the nonsmoking section can be altered by selective removal of compounds by cabin surfaces (e.g. nicotine, Figure 1) or by the presence of non-ETS sources of some species in the nonsmoking section, e.g. CO, RSP or NO_x (10).

In some cases exposure of the four volunteers to environmental tobacco smoke in the airport terminal was significant, Table I. In all cases, exposure to environmental tobacco smoke other than in the aircraft cabin or in the airport terminals was insignificant. The airport terminal exposure concentrations are very low for the after flight data for Flights 1 and 3 and the before flight data for Flights 2 and 4 because of minimal smoking and the open air nature of the airport terminal. Because of the significant concentration present in the airport terminal and the longer waiting period before Flight 1, Subjects C and D on this flight were exposed to more nicotine in the airport terminal than during the flight even though they tried to avoid cigarette smoke in the terminal, Table I.

A total dose exposure to nicotine, Table II, was calculated for each of the subjects on each of the flights from the measured concentrations of nicotine in the airport terminals and during the flights, and the time of exposure at each location. An average tidal volume of 8.5 L/min (17) was used in these calculations. The total cotinine excreted in the 24 hour period before each flight and in the first two 24 hour periods after each flight are given in Table II. The calculated dose is compared to the 48 hr excreted cotinine in Figure 2.

The amount of cotinine excreted during the first (X_1) and second (X_2) 24-hr periods after each flight can be used to calculate the fraction of the total to be excreted present in the first 24-hr sample. This number was constant for all volunteers where X_2 was measurable, 0.84±0.07, except subject A in Flight 1. The cotinine elimination half time of 9±2 hr agrees with the results of controlled exposure studies (14). Linear regression analysis of the data given in Figure 2 gives r=0.78 with a calculated slope of 0.13±0.03 mol cotinine/mol nicotine. The slope is consistent with the expected conversion of about 10% of the inhaled nicotine to excreted cotinine (14). The large uncertainty in the slope apparently results from individual variations in nicotine metabolism, Table II. These variations result in an uncertainty of a factor of 2 in the use of urinary cotinine to predict exposure to nicotine. However, the more rapid removal of nicotine as compared to other constitutents of environmental tobacco smoke in the cabin environment, Figure 1, results in larger errors in the use of cotinine to estimate exposure to these constituents. Such estimates are low by a factor of from 2-6 (10,17) for the data reported here.

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References

1. NAS "The Airliner Cabin Environment: Air Quality and Safety." National Research Council, National Academy Press, Washington, D.C., 303 pp (1986).

2. G.B. Oldaker III, M.W. Stancill, F.C. Conrad Jr., B.B. Collie, R.A. Fenner, S.O. Lephardt, P.G. Baker and S. Lyons-Hart Indoor Air Quality and Ventilation, Lanau F. and Reynolds G.L., eds, Selper Ltd, pp 442-454 (1990).

3. G.B. Oldaker III and F.C. Conrad Jr. Environ. Sci. Technol. 21: 994-999 (1987).

4. M.E. Mattson, G. Boyd, D. Byar, C. Brown, J.F. Callahan, D. Corle, J.W. Cullen, J. Greenblatt, N.J. Haley, S.K. Hammond, J. Lewtas and W. Reeves JAMA 261: 867-872 (1989).

5. T. Malmfors, D. Thorburn and A. Westlin A. Environmental Technology Letters 10: 613-628 (1989).

6. M. Muramatsu, S. Umemua, J. Fukui, T. Arai and S. Kira Int. Arch. Occup. Environ. Health 59: 545-550 (1987).

7. D. Foliart, N.L. Benowitz and C.E. Becker N. Engl. J. Med. 308: 1105 (1983).

8. D.J. Eatough, L.D. Hansen and E.A. Lewis Environmental Tobacco Smoke, Proceedings of the International Symposium at McGill University 1989, D. J. Ecobichon and J. M. Wu, Eds., Lexington Books, 1990, pp 3-39.

9. H. Tang, D.J. Eatough, E.A. Lewis, L.D. Hansen, K. Gunther, D. Belnap and J. Crawford, Measurement of Toxic and Related Air Pollutants, Air and Waste Management Association, pp 596-605 (1989).

10. D.J. Eatough, F.M. Caka, J. Crawford, S.K. Braithwaite, L.D. Hansen and E.A. Lewis. "Environmental Tobacco Smoke in Commercial Aircraft,"Proceedings, Indoor Air '90, submitted (1990).

11. D.J. Eatough, F.M. Caka, K. Wall, J. Crawford, L.D. Hansen and E.A. Lewis Measurement of Toxic and Related Air Pollutants, Air and Waste Management Association, pp 565-576 (1989).

12. F.M. Caka, D.J. Eatough, E.A. Lewis, H. Tang, S.K. Hammond, B.P. Leaderer, P. Koutrakis, J.D. Spengler, A. Fasano, M.W. Ogden and J. Lewtas "An Intercomparison of Sampling Techniques for Nicotine in Indoor Environments", Env. Sci. and Tech., in press (1990).

13. S.K. Hammond and B.P. Leaderer Environ. Sci. Tech. 21: 494-497 (1987).

14. E.A. Lewis, H. Tang, W. Winiwarter, K. Gunther, D. Belnap, A. Jensen, L.D. Hansen, D.J. Eatough, N.J. Balter and S.L. Schwartz. "Use of Urine Nicotine and Cotinine Measurements to Determine Exposure of Nonsmokers to Sidestream Tobacco Smoke," Proceedings, Indoor Air '90, submitted (1990b).

15. J.R. Carson and C.A. Erikson Environ. Tech. Letters 9: 501-508 (1988).

16. L.J. Lewis, J.D. Lamb, D.J. Eatough, L.D. Hansen and E.A. Lewis J. of Chrom. Sci. 28, 200-203 (1990a).

17. D.J. Eatough, F.M. Caka, J. Crawford, L.D. Hansen and E.A. Lewis, Report to the Center for Indoor Air Research (1990b).

ality and Safety." National
gton, D.C., 303 pp (1986).

rad Jr., B.B. Collie, R.A.
Hart Indoor Air Quality and
lper Ltd, pp 442-454 (1990).

n. Sci. Technol. 21: 994-999

.F. Callahan, D. Corle, J.W.
d, J. Lewtas and W. Reeves

A. Environmental Technology

ai and S. Kira Int. Arch.

M. Engl. J. Med. 308: 1105

nvironmental Tobacco Smoke.
Gill University 1989, D. J.
'90, pp 3-39.

ise Gunther, D. Belnap
ed ... Pollutants, Air and

raithwaite, L.D. Hansen and
Smoke in Commercial
(1990).

ford, L.D. Hansen and E.A.
Pollutants, Air and Waste

Tang, S.K. Hammond, B.P.
, M.W. Ogden and J. Lewtas
for Nicotine in Indoor
0).

Tech. 21: 494-497 (1987).

her, D. Belnap, A. Jensen,
. Schwartz. "Use of Urine
Exposure of Nonsmokers to
'90, submitted (1990b).

etters 9: 501-508 (1988).

nsen and E.A. Lewis J. of

. Hansen and E.A. Lewis,
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Table I. Concentrations of Total Nicotine from Environmental Tobacco Smoke to Which the Volunteers were Exposed Before, During and After Four DC-10 Flights.

Flight	Subject	Seat	Rows Before Smoking Section	Total Nicotine, nmol/m^3 (Exposure Time, hr) In Airport Before Flight	During Flight	In Airport After Flight
1	A	35D	0	58 (4.50)[a]	319 (4.87)[b]	>1 (1.20)[a]
	B	34G	0		208	
	C	32J	1		15.4	
	D	17D	16		0.1	
2	A	34C	0	>1 (1.0)[a]	84 (4.30)[b]	>1 (1.0)[a]
	B	33C	1		78	
	C	33A	1		39	
	D	24C	10		0.1	
3	A	32F	0	39 (1.87)[a]	475 (4.83)[b]	>1 (0.5)[a]
	B	31F	1		304	
	C	30D	2		127	
	D	26F	6		20.4	
4	A	35D	0	>1 (1.3)[a]	71 (4.55)[b]	13 (0.60)[a]
	B	33D	2		36	
	C	29C	6		12.2	
	D	24F	11		1.2	

[a]Both concentration and time were the same for all four volunteers.
[b]Time was the same for all four volunteers.

Table II. Nicotine Exposure and Cotinine in Urine for Each of the Volunteers Involved in the DC-10 Flights.

Flight	Subject	Inhaled Nicotine nmol	% of Exposure During Flight	Total Urinary Cotinine, nmol 24 Hr Before Flight	0-24 Hr After Flight	24-48 Hr After Flight	% of Inhaled Nicotine
1	A	925	86	<3	144	66	22.7
	B	650	80	152[a]	107[a]	19[a]	19.4
	C	171	22	NA[b]	NA[b]	NA[b]	NA
	D	133	0.2	<3	16	<3	11.9
2	A(C)[c]	184	100	NA[b]	NA[b]	NA[b]	NA
	B(B)	171	100	11		NA	NA
	C(A)	86	100				
	D(D)	0.2	100				
3	A	1207	97	<3	88	23	9.2
	B	786	95	<3	35	4	5.0
	C	350	89	<3	20	3	6.6
	D	87	57	<3	9	<3	9.9
4	A(C)	162	98				
	B(A)	88	95				
	C(B)	32	87	4	<3	<3	--
	D(D)	7	41	<3	3	<3	--

[a]Preflight exposure to nicotine resulted from work in the analytical lab and not from ETS. Subsequent data have been corrected for this exposure assuming a constant elimination half life.
[b]Cotinine could not be determined due to nitrogen containing interfering compounds.
[c]The letter in () is the identification for this volunteer in the previous flight.

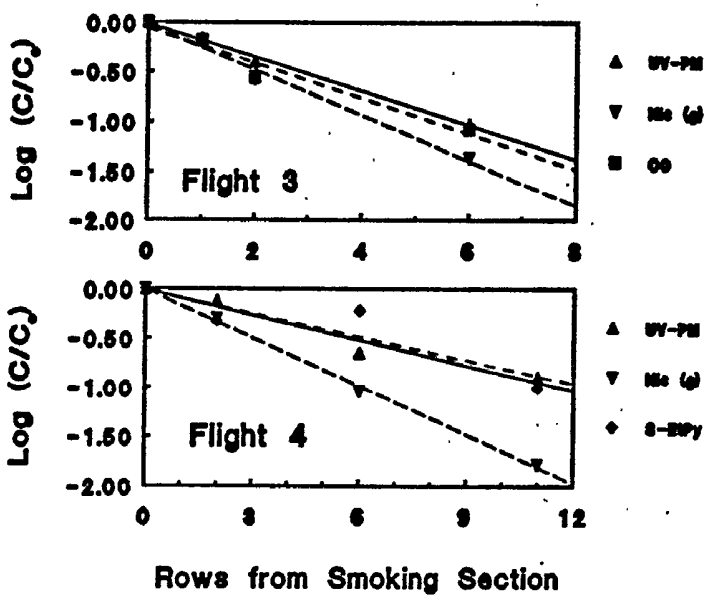

Figure 1. The $\log(C/C_o)$, where C_o is the concentration in the smoking section, versus number of rows from the nonsmoking section into the smoking section for Flights 3 (high exposure) and 4 (moderate exposure).

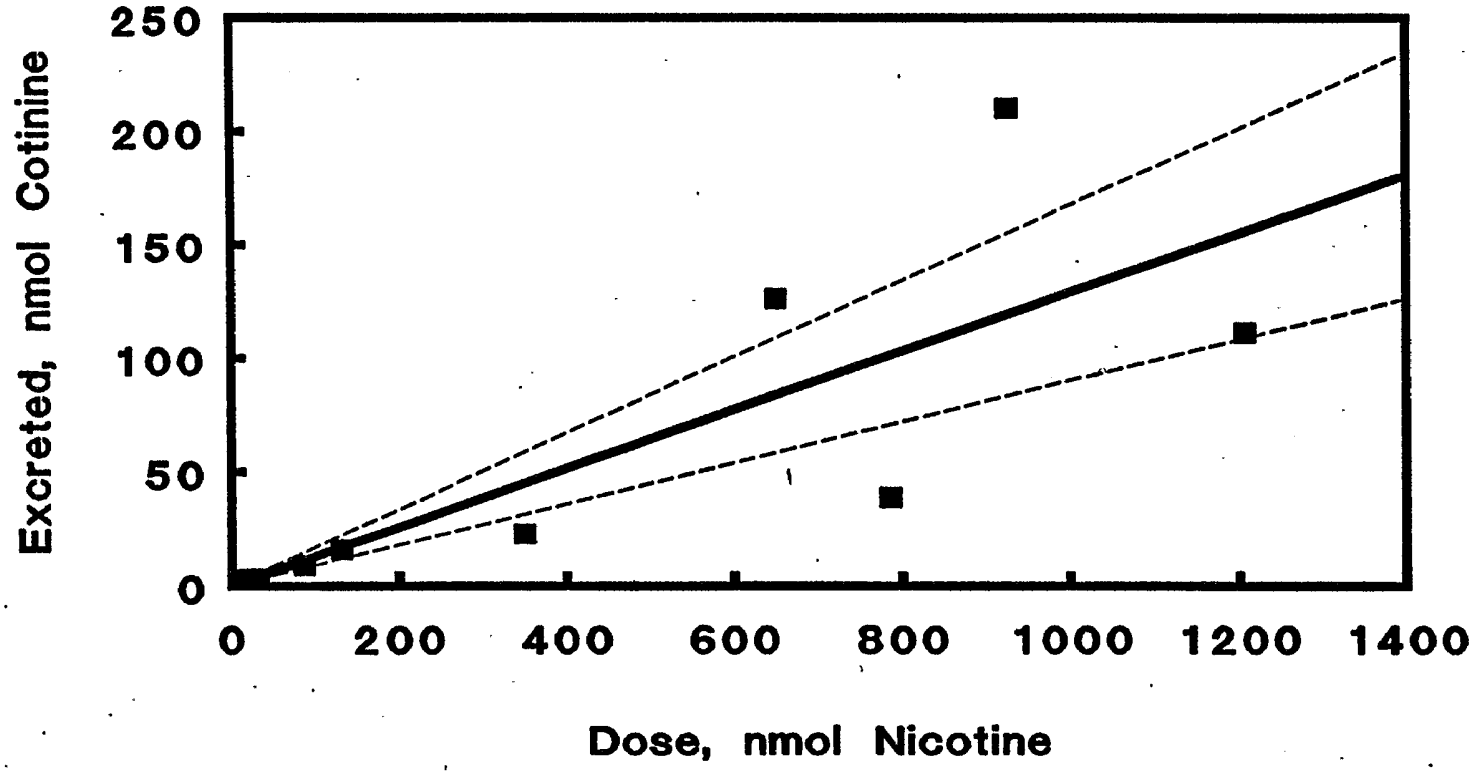

Figure 2. Total nicotine exposure vs cotinine excretion the 48 hours after the flight.

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