'Herbal' but potentially hazardous: an analysis of the constituents and smoke emissions of tobacco-free waterpipe products and the air quality in the cafés where they are served

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ABSTRACT

Background There are limited data on the composition and smoke emissions of 'herbal' shisha products and the air quality of establishments where they are smoked.

Methods Three studies of 'herbal' shisha were conducted: (1) samples of 'herbal' shisha products were chemically analysed; (2) 'herbal' and tobacco shisha were burned in a waterpipe smoking machine and main and sidestream smoke analysed by standard methods and (3) the air quality of six waterpipe cafés was assessed by measurement of CO, particulate and nicotine vapour content.

Results We found considerable variation in heavy metal content between the three products sampled, one being particularly high in lead, chromium, nickel and arsenic. A similar pattern emerged for polycyclic aromatic hydrocarbons. Smoke emission analyses indicated that toxic byproducts produced by the combustion of 'herbal' shisha were equivalent or greater than those produced by tobacco shisha. The results of our air quality assessment demonstrated that mean $PM_{2.5}$ levels and CO content were significantly higher in waterpipe establishments compared to a casino where cigarette smoking was permitted. Nicotine vapour was detected in one of the waterpipe cafés.

Conclusions 'Herbal' shisha products tested contained toxic trace metals and PAHs levels equivalent to, or in excess of, that found in cigarettes. Their mainstream and sidestream smoke emissions contained carcinogens equivalent to, or in excess of, those of tobacco products. The content of the air in the waterpipe cafés tested was potentially hazardous. These data, in aggregate, suggest that smoking 'herbal' shisha may well be dangerous to health.

BACKGROUND

Waterpipe use is increasing among young adults in North America.[1 2] While tobacco is the most common form of shisha used in waterpipe smoking, products described as 'tobacco free', '0% nicotine and 0% tar' or 'herbal' have become widely available. These latter forms of shisha are frequently described as 'healthy'. Terms such as 'relish hookah smoking experience the healthy way',[3] 'a healthier alternative to hookah molasses tobacco',[4] and 'the same flavourful smoke found in other shisha without the harmful effects of tobacco'[5] are prominent on company websites. Despite these statements, there is no substantive information provided on the constituents of the 'herbal' shisha products offered for sale or on the toxicants present in the main and sidestream smoke produced when they are burned in a waterpipe. Furthermore, there are limited data on the air quality of establishments where the use of 'herbal' shisha is sanctioned.

In a 45 min use episode, a waterpipe user inhales between 50 and 100 L of smoke[6 7] which has been found to contain large quantities of toxicants and carcinogens.[8–14] However, many waterpipe users believe that smoking the waterpipe is less harmful than smoking cigarettes,[15] often deriving this belief from the assumption that passage of the smoke through water eliminates the harmful substances normally associated with tobacco smoking.[9 16] Directly challenging this belief are studies of urinary biomarkers for carcinogens that have demonstrated that waterpipe use results in systemic exposure to carcinogens at levels similar to those experienced by cigarette smokers.[17] Furthermore, exposure to both tobacco and tobacco-free waterpipe smoke has also been shown to result in acute impairment of cardiac autonomic function in waterpipe users.[18]

In the last decade, evidence on the potential harmful effects of waterpipe use has continued to accumulate.[19] As a result, WHO has advised prohibition of waterpipe use in public spaces consistent with bans on cigarette use.[20] While authorities in North America have varyingly followed this advice, some hospitality venues have sought and won exemptions to tobacco smoking bans by serving ostensibly tobacco-free waterpipe products.[21 22] One challenge faced by these authorities is the scarcity of data on the toxicant emissions or health effects of secondhand smoke from tobacco-free waterpipe products. To date, no study has reported secondhand smoke emissions from tobacco-free waterpipe products, and only one study has reported toxicant content of mainstream smoke.[10]

The aim of this study was to provide an assessment of the chemical constituents of samples of tobacco-free, often referred to as 'herbal', products used in waterpipes in Canada. Additionally, we sought to describe the emissions produced when a sample of these herbal products are smoked under controlled conditions. Finally, we wished to determine if individuals not smoking a waterpipe, but present in a waterpipe café, were passively exposed to potentially toxic substances by measuring simple air quality markers ($PM_{2.5}$ and CO) in waterpipe cafés where 'herbal' waterpipe products were being smoked.

METHODS

'Herbal' shisha procurement and sample preparation

Samples of 'herbal' shisha labelled as '0.0% tar and 0.0% nicotine' or '100% tobacco free' were obtained from four different local retail outlets in Edmonton, Alberta, Canada. One standard flavour was selected (strawberry). Three brands of 'herbal' shisha that are widely available in Canada were randomly selected as 'herbal' shisha test products for the purposes of this study.

Nine 50-gram boxes each of Soex (India) and Hydro (USA), and three 250 g boxes of Zero n Zero (USA) were purchased. For each brand, the contents of the boxes were mixed together to form one base sample.

In the same retail outlets we purchased a supply of charcoal (Al-Fakher, China) for use in our smoke constituent experiments.

Characterisation of constituents of unburned 'herbal' shisha

Two 100 g samples of each brand were appropriately blind coded, packaged and shipped to a commercial analytical laboratory (Labstat International UCL, Kitchener, Ontario, Canada) for analysis. At the laboratory the samples were removed from the wrapping and three replicates of each of the brands supplied were used for extraction and analysis. Standard methods were used to evaluate the levels of nicotine,[23] heavy metals[24] and polycyclic aromatic hydrocarbons (PAHs).[25]

For nicotine content, a standard additions assay was performed on each replica for verification of the data. The content data from the shisha samples were compared with control data and, if the results were acceptable, an outlier test was performed. Outliers were analysed, and if an assignable cause for the deviation was discovered, the data point was removed. If no assignable cause was found, the outliers were included in the dataset and all subsequent calculations. The results of the three replicates were averaged in each case.

Smoke constituent analysis

Appropriately coded and packaged samples (200 g) along with a randomly selected sample of Al-Fakher charcoal were sent to the Aerosol Research Laboratory at American University of Beirut (AUB, Beirut, Lebanon) for mainstream and sidestream smoke emissions analysis.

A standard protocol was used to generate mainstream and sidestream smoke from the three test materials and a popular tobacco-containing shisha product (Two Apples, Nakhla Tobacco, Cairo, Egypt).[7] The Two Apple product was used for comparative purposes.

Briefly, waterpipe smoke was sampled using a smoking machine that can be digitally programmed. The machine split the smoke from the waterpipe into two streams using a computer-activated diaphragm pump. A standard smoking regimen of 171 puffs, each puff with a volume of 0.53 L, a 2.6 s duration, and a 17 s interpuff interval was used. The head of the waterpipe was filled with 10 g of sample product and a perforated aluminium foil sheet was used to cover the head. A burning quick-light charcoal disk was placed on the head of the waterpipe. For each product, five replicate smoking sessions were held. The amount of nicotine, CO, tar and PAHs was determined by following standardised procedures and using GC-MS and HPLC.[8 9 26]

Air quality measurements in waterpipe cafés

Six randomly selected cafés were covertly visited during evening hours on weekend days in Edmonton, Alberta, Canada. The research team followed a protocol for air quality assessment that has been previously used in similar settings.[27 28] A table near the middle of the venue, away from the corners, was selected (when possible), and a bag containing the concealed monitors was left resting on a seat at the table away from the direct stream of smoke emitting from any waterpipe. For comparison, a similar protocol was used on two separate occasions to measure air quality in a casino where cigarette smoking was permitted.

A SidePak personal aerosol real-time monitor (TSI, St Paul, Minnesota, USA) was used to measure $PM_{2.5}$. The $PM_{2.5}$ in waterpipe cafés was derived using a waterpipe-specific calibration factor of 0.37,[29] while in the casino the commonly used calibration factor for tobacco smoke (0.32) was used. CO and carbon dioxide (CO_2) concentrations along with the ambient humidity and temperature were simultaneously measured in these venues using the Q-Trak indoor air quality monitor (TSI, USA). Monitors were calibrated prior to each visit and set to record real-time measurements every 10 s during the visit. Air quality data was collected for 10 min outdoors before and after the visit for comparison and collected inside each café/casino for 1 h.

Nicotine concentration in the ambient air was determined using a passive sampling device Monitor of Nicotine (MoNIC) which was developed and supplied by the Institute of Occupational Health, Lausanne, Switzerland.[30] Nicotine badges were attached to the outside of the sampling monitor bags during the 1 h sampling period. After the visit, the badges were placed into air tight containers until shipped for analysis. Badges were analysed by methods previously described.[31]

The room size and ceiling heights were measured using tile size/count along with a Zircon Sonic Measure (DM S50L, Campbell, California, USA) to determine the room volume. Number of occupants and burning waterpipes were recorded every 10 min. Other possible sources of CO, CO2 and $PM_{2.5}$ within the smoking venue were documented. Ventilation rates were estimated using the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) equation.[28 32] Analyses were conducted using the Statistical Program for the Social Sciences (SPSS) V.19.0 (IBM SPSS, Armonk, New York, USA).

RESULTS

Constituents of unburned 'herbal' shisha

There was high variability in toxicant content among analysed 'herbal' products as shown in table 1. For example, lead and arsenic levels were below the limit of quantification (NQ) in two brands, and in the third they were 438 ng/mg and 281 ng/mg, respectively. Chromium levels among the three products tested ranging from 160 ng/mg to 2190 ng/mg, and nickel levels ranged from 150 ng/mg to 626 ng/mg. Similar findings were seen for PAHs concentrations with naphthalene levels ranging from 14.5 ng/mg in one product to 32.2 ng/mg in another; benzo(a) anthracene ranging from 0.4 ng/mg to 5.68 ng/mg; chrysene ranging from 1.0 ng/mg to 11.1 ng/mg and benzo(a)pyrene levels ranging from NQ to 6.33 ng/mg. No nicotine was detected in any of the tested products.

Table 1 'Herbal' products content analysis

Product constituent	Product A (Zero-zero) Average (SD)	(95% CI)	Product B (Soex) Average (SD)	(95% CI)	Product C (Hydro) Average (SD)	(95% CI)
Toxic trace metals (ng/g)						
Cadmium	BDL	N/A	BDL	N/A	BDL	N/A
Lead (2B)*	BDL	N/A	NQ	N/A	438 (8)	418–458
Chromium (1)*	160 (28)	91.9 to 229	401 (13)	367 to 434	2190 (517)	906 to 3475
Nickel (1,2B)*	150 (10)	126 to 174	158 (9)	136 to 181	626 (33)	544 to 708
Arsenic (1)*	NQ	N/A	NQ	N/A	281 (27)	214–349
Selenium	BDL	N/A	BDL	N/A	BDL	N/A
Mercury	BDL	N/A	BDL	N/A	BDL	N/A
Nicotine (mg/g)						
Nicotine	BDL	N/A	BDL	N/A	BDL	N/A
Polyaromatic hydrocarbons, PAHs (ng/g)						
Naphthalene (2B)	32.2 (10.0)	7.32 to 57.1	23.9 (4.5)	12.7 to 35.0	14.5 (3.9)	4.73 to 24.2
1-methylnaphthalene	36.9 (8.4)	16.0 to 57.9	27.7 (1.9)	22.9 to 32.5	11.3 (3.2)	3.38 to 19.1
2-methylnaphthalene	16.9 (3.0)	9.54 to 24.3	19.2 (2.7)	12.4 to 25.9	7.48 (2.23)	1.95 to 13.0
Acenaphthylene	1.21 (0.10)	0.95 to 1.47	0.59 (0.22)	0.05 to 1.13	2.82 (0.76)	0.927 to 4.72
Acenaphthene	0.76 (0.22)	0.22 to 1.29	1.23 (0.42)	0.19 to 2.26	NQ	N/A
Fluorene	3.29 (0.26)	2.65 to 3.93	2.79 (1.26)	0.00 to 5.92	4.95 (1.25)	1.85 to 8.05
Phenanthrene	3.78 (0.91)	1.53 to 6.03	13.7 (2.5)	7.40 to 19.9	20.1 (2.8)	13.1 to 27.0
Anthracene	0.58 (0.09)	0.35 to 0.81	0.34 (0.14)	0.00 to 0.68	1.41 (0.19)	0.943 to 1.87
Fluoranthene	4.87 (1.11)	2.11 to 7.63	3.07 (0.45)	1.94 to 4.20	20.1 (1.8)	15.6 to 24.6
Pyrene	3.88 (0.71)	2.11 to 5.65	4.35 (0.27)	3.69 to 5.00	17.9 (0.9)	15.6 to 20.2
Benzo(a)anthracene(2B)	0.38 (0.09)	0.16 to 0.61	1.28 (0.20)	0.79 to 1.78	5.68 (0.43)	4.61 to 6.75
Chrysene(2B)	1.03 (0.18)	0.57 to 1.49	7.12 (0.35)	6.24 to 8.00	11.1 (0.7)	9.25 to 12.9
Benzo(b)fluoranthene(2B)	NQ	N/A	1.07 (0.20)	0.59 to 1.56	9.85 (0.56)	8.45 to 11.3
Benzo(k)fluoranthene(2B)	NQ	N/A	NQ	N/A	4.41 (0.07)	4.22 to 4.59
Benzo(j)fluoranthene(2B)	NQ	N/A	NQ	N/A	4.54 (0.16)	4.15 to 4.92
Benzo(e)pyrene	0.29 (0.15)	0.00 to 0.65	1.63 (0.14)	1.28 to 1.98	7.25 (0.41)	6.24 to 8.25
Benzo(a)pyrene(1)	NQ	N/A	0.53 (0.15)	0.16 to 0.91	6.33 (0.69)	4.63 to 8.03
Perylene	BDL	N/A	NQ	N/A	1.53 (0.22)	0.995 to 2.08
Indeno(1,2,3-cd)pyrene(2B)	NQ	N/A	NQ	N/A	6.26 (0.38)	5.32 to 7.19
Dibenz(a,h)anthracene(2A)	BDL	N/A	BDL	N/A	0.71 (0.07)	0.54 to 0.88
Benzo(g,h,i)perylene	NQ	N/A	0.49 (0.20)	0.001 to 0.99	8.23 (0.74)	6.38 to 10.1
pH						
pH	5.96 (0.00)	5.95 to 5.97	3.64 (0.00)	3.63 to 3.65	5.10 (0.01)	5.07 to 5.14
Moisture (%)						
Dry matter	76.0 (0.2)	75.5 to 76.6	69.3 (0.8)	67.4 to 71.3	80.9 (0.1)	80.5 to 81.2
Moisture	24.0 (0.2)	23.4 to 24.5	30.7 (0.8)	28.7 to 32.6	19.1 (0.1)	18.8 to 19.5

*IARC classified: Group 1, carnicognic to humans; Group 2A, probably carcinogenic to humans; Group 2B, possibly carcinogenic to humans.
BDL, below the limit of detection; IARC, International Agency for Research on Cancer; N/A, not applicable; NQ, below the limit of quantification; PAH, polycyclic aromatic hydrocarbon.

Smoke constituents

Mainstream smoke emissions of 'herbal' shisha products tested contained substantial quantities of toxicants with considerably varying concentrations between brands, and in virtually all cases equalled or exceeded concentrations found when the smoke produced by the tobacco comparator was analysed (table 2). For example, tar levels were 909 mg/session for tobacco versus 1080, 1260, 2350 mg/session for 'herbal' shisha; and benzo(a) pyrene levels were 96 ng/session for tobacco versus 95, 86 and 140 ng/session for 'herbal' shisha.

Analyses of sidestream smoke emissions showed similar findings (table 3). For example, ultrafine particulate levels were 4.9×10^{12}/session for tobacco versus 5.2, 3.7 and 5.3×10^{12}/session for the 'herbal' brands; benzo(a)pyrene levels were 66 ng/session for tobacco versus 108 ng, 90 ng and 121 ng for the 'herbal' brands.

Air quality in cafés

The characteristics of the visited venues, average number of occupants, average number of active waterpipes, ventilation rates (Vo), waterpipe density (Ds) (# active waterpipes/venue volume in 100 m^3) and the ventilation-adjusted waterpipe density (Ds/Vo: ((# active waterpipes/venue volume in 100 m^3)/ventilation rate) are summarised in table 4. No other sources of $PM_{2.5}$ such as an open grill or cooking fire were observed in the smoking areas where the measurements were obtained. Mean $PM_{2.5}$ levels across all waterpipe cafés ranged from 14 to 430 μg/m^3. The overall mean level of $PM_{2.5}$ in the waterpipe smoking establishments was 264 μg/m^3 (±214) with a range of 1–2675 μg/m^3. This was significantly higher than the comparison cigarette smoking venue—mean of 215 μg/m^3 (±165) with a range of 2–726 μg/m^3; $p<0.001$. The overall mean level of CO in waterpipe smoking establishments was 6.7 ppm (±4.5) with a range of

Table 2 Mainstream smoke analysis

	Tobacco*	Product A (Zero-zero)*		Product B (Soex)*		Product C (Hydro)*	
Repeated runs (N)	5	6		5		5	
Toxicant emissions (per waterpipe)	Mean (SD)	Mean (SD)	p Value†	Mean (SD)	p Value†	Mean (SD)	p Value†
Carbon monoxide, (mg)	197 (13.1)	286 (42)	0.001	237 (42)	0.08	269 (17)	<0.001
Nitric oxide, (mg)	0.28 (0.04)	0.35 (0.03)	0.006	0.32 (0.02)	0.002	0.35 (0.06)	0.03
Tar, (mg)	909 (195)	1080 (238)	0.2	1260 (233)	0.03	2350 (324)	<0.001
Volatile Aldehydes, (μg)							
Formaldehyde	36.0 (6.25)	41 (14)	0.5	66.0 (9.68)	0.0004	111 (29)	<0.001
Acetaldehyde	492 (88)	604 (159)	0.2	348 (70)	0.02	933 (239)	0.04
Acrolein	ND	ND		26.7 (27)	0.06	203 (182)	0.04
Propionaldehyde	92.9 (16.7)	105 (35)	0.5	59 (11.7)	0.006	181 (65)	0.02
Methacrolein	19.9 (2.63)	20 (6)	1	22.92 (4.6)	0.4	25 (6)	0.1
Polyaromatic hydrocarbons, (ng)							
Naphtalene	230 (64)	266 (101)	0.5	176 (15)	0.1	269 (60)	0.3
Acenaphtylene	74 (13)	66 (14)	0.8	44 (8)	0.002	62 (15)	0.2
Acenaphtene	ND	ND		ND		ND	
Phenanthrene	1185 (246)	1445 (364)	0.2	660 (148)	0.004	1275 (266)	0.6
Anthracene	234 (44)	243 (59)	0.8	144 (30)	0.005	253 (56)	0.6
Fluoranthene	639 (118)	796 (202)	0.2	496 (110)	0.08	891 (248)	0.07
Pyrene	564 (103)	719 (193)	0.1	471 (118)	0.2	854 (211)	0.02
Benzo[a]anthracene	130 (27)	183 (56)	0.09	144 (27)	0.4	293 (84)	0.003
Chrysene	135 (24)	210 (57)	0.02	161 (28)	0.1	279 (59)	0.001
Benzo[k+b]fluoranthene	72 (10)	92 (23)	0.1	71 (15)	0.9	145 (25)	<0.001
Benzo[a]pyrene	96 (21)	95 (20)	0.9	86 (18)	0.4	140 (30)	0.03
Benzo[g,h,i]perylene	57 (10)	64 (15)	0.4	50 (12)	0.3	88 (12)	0.002
Indeno[1,2,3-cd]pyrene	69 (9)	84 (20)	0.2	66 (15)	0.7	107 (11)	<0.001

*10 g of the product.
†p Value; for 'herbal' products compared with tobacco.
ND, not detectable.

0–18 ppm. This was significantly higher than that in the cigarette smoking venue, where mean CO levels were 0.4 ppm (±0.4) with a range of 0–2 ppm; $p<0.001$ (table 5, figure 1).

Nicotine vapour concentrations were below detectable limits in five out of six waterpipe smoking venues tested. In one location, the nicotine amount absorbed by the nicotine badge was 0.15 mg, indicating the combustion of tobacco on the premises. This amount of nicotine is equivalent to the passive inhalation of 0.75 of a cigarette. No cigarette smoking was observed at any of the waterpipe smoking venues. Nicotine concentrations detected during each of the two visits to the casino were 0.22 and 0.29 mg (equivalent to the passive inhalation of 1 and 1.5 cigarettes, respectively).

DISCUSSION

This is the first comprehensive assessment of the constituents of unburned 'herbal' shisha. Additionally, we have determined the composition of the mainstream and sidestream smoke produced by the combustion of such products in a waterpipe and in a convenience sample, the quality of the air in venues where 'herbal' waterpipes are smoked in Canada. Our results showed high variability in constituents of different 'herbal' products analysed. When smoked under simulated conditions, 'herbal' products yield higher levels of toxicants including tar, PAHs, ultrafine particles and aldehydes compared to tobacco products. Our findings indicate that the ambient air quality of waterpipe cafés is potentially unhealthy, containing high concentration of $PM_{2.5}$ and CO. In one of six waterpipe cafés visited we found evidence of nicotine vapour suggesting that nicotine-containing shisha was being smoked on the premises.

The International Agency for Research on Cancer (IARC) classifies heavy metals and PAHs as carcinogenic or possibly carcinogenic to humans.[33] Our data reveal that 'herbal' shisha, depending on the brand, may contain significant concentrations of these substances. If one compares our data for 'herbal' shisha with those of cigarettes by Hammond *et al*[34] the findings are instructive: one of the 'herbal' products we tested contained more than four times the concentration of chromium, twice that of nickel and greater amounts of lead and arsenic than what was found in Canadian cigarettes. Similarly, the amount of Benzo(a) pyrene that was found in one 'herbal' product was comparable with Canadian cigarettes.[34] The other two products tested were more benign, however, the lack of standardisation of content and information about the constituents is a concern. For each tobacco product sold in Canada, Health Canada requires disclosure of 26 chemical constituents including heavy metals and 41 smoke emissions.[34 35] Unfortunately, thus far, these requirements are not imposed on 'herbal' products smoked in a waterpipe.

The consumption of 'herbal' shisha results in the emission of an array of toxicants including CO, NO, tar, volatile aldehydes and PAHs. Empirical data have previously shown emission of high levels of toxicants from waterpipe tobacco use.[7 9 36] The current study reports about the constituents of mainstream and sidestream smoke produced when 'herbal' shisha are burned.[10] Our findings for 'herbal' shisha mirror, to a degree, data from

Table 3 Sidestream smoke analysis

	Tobacco*	Product A (Zero-zero)*		Product B (Soex)*		Product C (Hydro)*	
Repeated runs (N)	5	6		5		5	
Toxicant emissions(per waterpipe)	Mean (SD)	Mean (SD)	p Value†	Mean (SD)	p Value†	Mean (SD)	p Value†
Carbon monoxide, (mg)	1880 (151)	2912 (256)	<0.001	2560 (280)	0.001	2825 (267)	<0.001
Nitric oxide, (mg)	4.5 (0.12)	4.91 (0.48)	0.8	5.75 (0.48)	<0.001	5.66 (0.46)	<0.001
Nanoparticles, (10^{12})	4.8 (0.43)	5.18 (0.56)	0.3	3.73 (0.59)	0.009	5.32 (0.62)	0.2
Volatile aldehydes, (μg)							
Formaldehyde	4285 (836)	2220 (389)	<0.001	2270 (372)	0.001	2724 (286)	0.004
Acetaldehyde	1690 (405)	2427 (758)	0.09	1200 (264)	0.05	2963 (869)	0.02
Acrolein	210 (64.9)	257 (97)	0.4	245 (60)	0.4	838 (293)	0.002
Propionaldehyde	142 (39)	241 (80)	0.03	116 (41)	0.3	241 (110)	0.09
Methacrolein	45 (12)	50 (25)	0.7	37.8 (6.44)	0.3	60 (25)	0.3
Polyaromatic hydrocarbons, (ng)							
Naphtalene	87 (29)	69 (29)	0.3	82 (21)	0.8	89 (14)	0.9
Acenaphtylene	ND	ND		ND		ND	
Acenaphtene	ND	ND		ND		ND	
Phenanthrene	60 (10)	156 (94)	0.05	61 (18)	0.9	191 (67)	0.003
Anthracene	27 (25)	56 (15)	0.04	51 (9)	0.08	63 (13)	0.02
Fluoranthene	66 (12)	188 (144)	0.09	59 (23)	0.6	235 (96)	0.005
Pyrene	77 (12)	201 (138)	0.08	75 (25)	0.9	256 (107)	0.006
Benzo[a]anthracene	30 (4)	87 (39)	0.01	38 (20)	0.4	109 (45)	0.005
Chrysene	52 (7)	136 (58)	0.01	63 (23)	0.3	161 (56)	0.003
Benzo[k+b]fluoranthene	70 (11)	126 (32)	0.005	100 (26)	0.05	130 (32)	0.004
Benzo[a]pyrene	66 (8)	108 (23)	0.004	90 (16)	0.02	121 (27)	0.002
Benzo[g,h,i]perylene	104 (17)	116 (19)	0.3	125 (31)	0.2	122 (27)	0.2
Indeno[1,2,3-cd]pyrene	150 (18)	174 (31)	0.2	164 (33)	0.4	185 (34)	0.08

*10 g of the product.
†p Value; for 'herbal' products compared with tobacco.
ND, not detectable.

studies of smoke produced by herbal cigarettes, particularly with respect to PAH production.[37]

For all three products, we found that the mainstream and sidestream smoke produced significant quantities of CO. Of particular significance was the more than sixfold increase in CO found in sidestream relative to mainstream smoke, suggesting that passive exposure to CO by non-participants could be considerable, a finding confirmed by our air quality analysis (vide infra). Although CO symptoms of toxicity can be non-specific (dizziness, irritability, confusion/memory loss, disorientation, nausea and vomiting, syncope, difficulty coordinating and breathing and chest pain), prolonged exposure can lead to more serious effects including myocardial infarction, cerebral oedema, coma, and death.[38] Waterpipe smoking yields high levels of CO in the smoke, and carbonmonoxyhaemoglobin (COHb) levels in waterpipe smokers' blood have been shown to be higher than in other forms of smoking.[39] A number of case reports have detailed early CO toxicity in waterpipe smokers, some presenting

Table 4 Waterpipe café parameters and ventilation rates

Venue	Area (m^2); ceiling height (m)	Volume (m^3)	Ave. occupants	Ave. person/ 100 m^2	Ave. # active waterpipes (AAW)	CO_2 indoors—outdoors (ppm)	Vo=G/(Cs-Co) ventilation rate per person	Est. (AWP) %	Ds W density (AAW/ 100 m^3)	Ds/Vo Ventilation adj. W density
WP1	164;3.8	623	36	22.0	12	860−384=476	5000/476=11	33	1.9	0.18
WP2	131;2.7	354	54	41	21	740−358=382	5000/382=13	39	5.9	0.45
WP3	110;4.27	471	43	39	24	844−417=427	5000/427=12	56	5.1	0.44
WP4	112;3.05	340	38	34	17	840−498=342	5000/342=15	45	5	0.34
WP5	70;6.0	422	13	19	7	1563−430=1133	5000/1133=4	56	1.7	0.39
WP6	227;2.9	804	16	5.77	4.2	648−379=269	5000/269=19	26	0.5	0.03
CIG A	5800;4.5	26 100	418	7.21	43*	539−349=190	5000/187=26	10*	0.16	0.01
CIG B	5800;4.5	26 100	528	9.10	50*	493−325=168	5000/168=30	9*	0.19	0.01

*Cigarettes instead of waterpipes.
AAW, average active waterpipes (ie, average number of active waterpipes during the period of visit); AWP, active waterpipe percentage (ie, average active waterpipes/occupants)×100 waterpipe Ds is AAW/100 m^3; CIG, cigarette smoking venues; Co, the CO_2 level outdoor; Cs, the CO_2 level in the building; Ds, w density (ie, AAW/100 m^3); G, 5000 ppm-L/s-person, (the generation rate of CO_2 for a sedentary person); Vo, ventilation rate per person; Vo, G/(Cs-Co); W, waterpipe; WP, waterpipes cafe.

Table 5 Average real-time air quality measures

Venue	Ave. $PM_{2.5}$ indoor (μg/m³)	Ave. $PM_{2.5}$ outdoor (μg/m³)	Ave. $PM_{2.5}$ in—out (μg/m³)	Ave. CO indoor (ppm)	Ave. CO outdoor (ppm)	Ave. CO in—out (ppm)
WP1	385	10	375	10.2	0.00	10.2
WP2	140	2	138	11.4	0.00	11.4
WP3	430	10	420	6.9	0.18	6.72
WP4	299	11	288	1.8	0.25	1.55
WP5	59	11	48	3.1	0.75	2.35
WP6	14	10	4	1.9	0.04	1.86
CIG A	219	5	214	0.43	0.03	0.4
CIG B	213	3	210	0.37	0.01	0.36

Indoor: average of 60 min.
Outdoor: average of 20 min.
CIG, cigarette smoking venues; WP, waterpipes cafe.

to emergency rooms with arterial COHb levels approaching 30%.[40 41]

We demonstrated a variation in toxicant production in mainstream smoke depending on the product tested. Interestingly, although all three of the 'herbal' brands tested were described on the exterior labelling as containing '0% tar', our analysis showed that levels of tar in mainstream smoke produced on combustion of these materials was considerable and far in excess of that experienced by cigarette smokers smoking single cigarettes.[34]

Volatile aldehydes exposure has been associated with respiratory disorders,[11] can cause irritation in the respiratory tract,[42] and contributes to the development of lung cancer and chronic obstructive pulmonary disease.[43] According to the IARC, formaldehyde is classified as a human carcinogen implicated in causing nasopharyngeal cancer and leukaemia.[44] Acrolein is considered a major cigarette-related lung cancer agent and one of the most mutagenic aldehydes in cigarette smoke.[45] Acrolein levels in Canadian cigarette smoke have been reported at 71.7 (21.1) μg/cig.[34] Our analysis revealed high production of the aforementioned volatile aldehydes during the smoking of 'herbal' shisha.

A study of ultrafine particles in cigarette smoke found that the particles yield ranged between 2.6×10^6 particles per cigarette for cigarettes manufactured by Phillip Morris, and 8.8×10^9 particles per cigarette by Marlboro Red.[46] In our results, the yield was higher and ranged between 3.7×10^{12} and 5.3×10^{12} for 'herbal' waterpipe and 4.8×10^{12} in tobacco waterpipe.

In our study, there were greater numbers of smokers and less ventilation per unit area in the waterpipe venues than in the casino where cigarettes were smoked. Despite these differences, the level of exposure to $PM_{2.5}$ in the casino location was still considerable. Consistent with previous reports,[26] in our analysis of mainstream and sidestream smoke we found greater ultrafine particles and other toxicant emissions from waterpipe smoke compared to reported emissions from a single cigarette. However, because a typical waterpipe use episode is between 45 min and 1 h in duration, and a cigarette may be smoked over as short an interval of 5 min, comparing mainstream and sidestream emissions per unit smoked may lead to confusion. A more understandable and obvious metric may be toxicant emissions per smoker hour. Using this approach (emissions per one person hour), Daher *et al*[26] demonstrated that a waterpipe user releases into the environment approximately twice the amount of aldehydes and PAHs and 10 times the amount of CO than an average cigarette user (two cigarettes per hour) over the equivalent time period.

One goal of smoke-free legislation is to protect individuals from secondhand smoke exposure and the associated increased risk for coronary artery disease, lung cancer and respiratory infections.[47] Although the ventilation rates for all visited venues, except one, fall within the ASHRAE acceptable standards,[32] our snapshot of the air quality in the waterpipe cafés visited indicated high $PM_{2.5}$ levels (mean 264 μg/m³; maximum 2675 μg/m³). Comparable levels of $PM_{2.5}$ were reported with cigarette and waterpipe tobacco smoking venues in both Syria (464 μg/m³)[48] and Lebanon (349 μg/m³),[49] and in waterpipe smoking venues in the USA (374 μg/m³).[27]

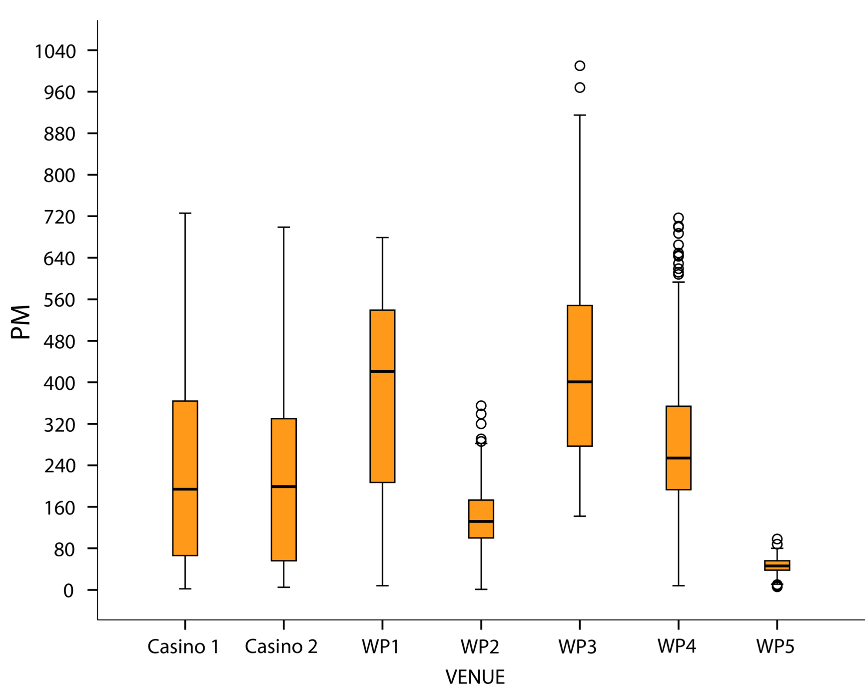

Figure 1 $PM_{2.5}$ levels (μg/m³) of exposure in waterpipe cafés compared with cigarette smoking venues.

Although our research team did not observe any other possible sources of $PM_{2.5}$ in the areas where measurements were obtained, the existence of such sources could not be ruled out in sites visited, especially from adjacent kitchen spaces. However, data from a recent study comparing $PM_{2.5}$ levels in waterpipe smoking and smoke-free restaurants found that $PM_{2.5}$ levels in the former were significantly higher than in the latter.[27] These data lend support to our findings, as in both locations one would expect to find comparable non-waterpipe sources of $PM_{2.5}$.

The potential health effects of repeated long-term exposure to high levels of $PM_{2.5}$ include an increased cardiovascular risk and mortality, inflammatory lung injury and subclinical atherosclerosis.[50 51] Moreover, uncertainties exist related to the consequences of short-term exposures to $PM_{2.5}$, but there is strong evidence that even brief exposure can trigger an acute event in patients with angiographically documented coronary artery disease.[52] In asthmatic patients, exposure to approximately 200 μg/m^3 $PM_{2.5}$ for 2 h increased inflammatory mediators.[53] A cohort study found an association between ambient $PM_{2.5}$ and levels of C-reactive protein, an indicator related to increased risk of coronary events.[54] In another study, *Urch et al*[55] demonstrated that controlled short-term (2 h) chamber exposures to 147 (±27) μg/m^3 ambient $PM_{2.5}$ and 239 (±6) μg/m^3 ozone in 23 normal, non-smoking healthy adults significantly increased diastolic blood pressure (DBP) compared with filtered air, with a strong association between the 2 h change in DBP and the organic carbon fraction of the $PM_{2.5}$.

Canada uses an Air Quality Health Index (AQHI)[56] to help the public understand what ambient air quality means to their health. It measures ambient air quality in relation to health on a scale from 1 to 10; the higher the number, the greater the health risk. A category that describes the level of health risk as 'high' is at the upper end of the scale, from 7 to 10. A 1 h average $PM_{2.5}$ level of 200 μg/m^3 which was easily exceeded in three of the six waterpipe cafés tested in our study (table 5) corresponds to an AQHI ~10 and indicates that $PM_{2.5}$ in air in these waterpipe cafés represents a potentially hazardous exposure.

We did not find any nicotine in the 'herbal' products tested, however, we did detect nicotine vapour in the ambient air at one of the waterpipe cafés visited. Waterpipe cafés are exempted from clean air legislation provided that tobacco products are not smoked on site; however, our findings suggest that violations may be occurring.

Waterpipe smoking is a practice that carries with it the real risk of changing the social norms regarding its use, normalising tobacco use, and undermining tobacco control efforts. Our recent survey of medical students at the University of Alberta revealed that current waterpipe smoking among this health-educated group was double the cigarette smoking, with most respondents indicating that they choose to smoke tobacco in their waterpipes.[57] Furthermore, waterpipe use could be a gateway for other forms of tobacco and drug use, and could be the cause of relapse for smokers who quit smoking cigarettes.[58] Given our findings and the accumulating evidence on the air quality in the waterpipe smoking venues,[27 59] the exemption of waterpipe cafés from smoke-free places legislation is a concern and reinforces the call for changes to current law.[21 22 60]

CONCLUSION

High levels of toxicants that are classified as carcinogenic, or known to have harmful effects on health, are present in 'herbal' shisha sold in Canada. The mainstream and sidestream smoke produced when these products are burned in a waterpipe contain numerous carcinogens and potentially unhealthy concentrations of CO and tar. The air quality of waterpipe cafés is in consequence less than optimal. These findings do not support the common belief that smoking 'herbal' shisha is a safe and healthy alternative for smoking tobacco waterpipe. To the contrary, 'herbal' waterpipe products produce many of the major tobacco disease-related toxicants in equal or greater quantities as their tobacco-based counterparts.

What this paper adds

- There is great variability in the composition of "herbal" shisha which can contain toxic trace metals and other carcinogens in excess of that found in cigarettes.
- The mainstream and sidestream smoke produced when "herbal" shisha is burned contains carcinogens equivalent to, or in excess of, those of tobacco products.
- The air quality in commercial venues where "herbal" is smoked is potentially hazardous, as it may contain significant amounts of ultrafine particulate matter.

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Contributors FH contributed to the study design and methods, data analysis, drafting the article, provided critical revisions to the article and gave final approval for publication. AC contributed to methods development, acquisition of data, provided critical revisions to the article and gave final approval for publication. TCW assisted in the study design, provided critical revisions to the manuscript and gave final approval for publication. WK assisted in the study design and methods, analysis of the results, provided critical revisions and gave final approval for publication. AS assisted in the study design and methods, analysis of the results, provided critical revisions to the article and gave final approval for publication. AV contributed to the methods development, data acquisition, provided critical revisions to the article and gave final approval for publication. CKH assisted in the nicotine vapour analysis, provided critical revisions to the article and gave final approval for publication. GP assisted in the nicotine vapour analysis, provided critical revisions to the article and gave final approval for publication. BAF was the principal investigator. He was responsible for the study conception and design, data interpretation, provided critical revisions to the article and gave final approval for publication.

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