Waterpipe Tobacco and Cigarette Smoking
Direct Comparison of Toxicant Exposure

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Background: Waterpipe (hookah, shisha) tobacco smoking has spread worldwide. Many waterpipe smokers believe that, relative to cigarettes, waterpipes are associated with lower smoke toxicant levels and fewer health risks. For physicians to address these beliefs credibly, waterpipe use and cigarette smoking must be compared directly.

Purpose: The purpose of this study is to provide the first controlled, direct laboratory comparison of the toxicant exposure associated with waterpipe tobacco and cigarette smoking.

Methods: Participants (N=31; M=21.4 years, SD=2.3) reporting monthly waterpipe use (M=5.2 uses/month, SD=4.0) and weekly cigarette smoking (M=9.9 cigarettes/day, SD=6.4) completed a crossover study in which they each smoked a waterpipe for a maximum of 45 minutes, or a single cigarette. Outcome measures included expired-air carbon monoxide (CO) 5 minutes after session's end, and blood carboxyhemoglobin (COHb), plasma nicotine, heart rate, and puff topography. Data were collected in 2008–2009 and analyzed in 2009.

Results: On average, CO increased by 23.9 ppm for waterpipe use (SD=19.8) and 2.7 ppm for cigarette smoking (SD=1.8), while peak waterpipe COHb levels (M=3.9%, SD=2.5) were three times those observed for cigarette smoking (M=1.3%, SD=0.5; p's<0.001). Peak nicotine levels did not differ (waterpipe M=10.2 ng/mL, SD=7.0; cigarette M=10.6 ng/mL, SD=7.7). Significant heart rate increases relative to pre-smoking were observed at 5, 10, 15, 20, 25, and 35 minutes during the cigarette session and at 5-minute intervals during the waterpipe session (p's<0.001). Mean total puff volume was 48.6 L for waterpipe use as compared to 1.0 L for cigarette smoking ($p<0.001$).

Conclusions: Relative to cigarette smoking, waterpipe use is associated with greater CO, similar nicotine, and dramatically more smoke exposure. Physicians should consider advising their patients that waterpipe tobacco smoking exposes them to some of the same toxicants as cigarette smoking and therefore the two tobacco-smoking methods likely share some of the same health risks.

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Introduction

Smoking tobacco using a waterpipe (hookah, narghile, shisha; Figure 1) is a global phenomenon,[1] especially among adolescents and young adults. For example, among adolescents, current waterpipe tobacco smoking prevalence is approximately 30% in Estonia[2]; Latvia[3]; and Beirut, Lebanon[4]; 5%–17% of some adolescent populations in the U.S. may be current waterpipe tobacco smokers.[5,6] Among university students, current waterpipe tobacco-smoking prevalence is 33% in Karachi, Pakistan,[7] and 10%–20% in the U.S.[8,9] Where no data are available, waterpipe tobacco smoking's popularity is demonstrated by businesses that facilitate it (e.g., hookah cafés) in countries such as Australia, Brazil, Canada, France, New Zealand, and South Africa. Thus, physicians across the globe can expect that some of their patients are current waterpipe tobacco smokers. The more informed these physicians are about the risks of this tobacco use method, the better they can address these risks with their waterpipe-using patients.

One way of estimating waterpipe risk is to compare waterpipe-smoke toxicant content (or yield) to cigarette-smoke toxicant content. Such comparisons are made using smoke generated by a machine and reveal that, relative to smoke generated from a cigarette, the smoke generated from a waterpipe yields alarming quantities of carcinogens; carbon monoxide (CO); nicotine; and "tar."[10–12] However, machine-generated smoke toxicant yields may not be an accurate indication of actual

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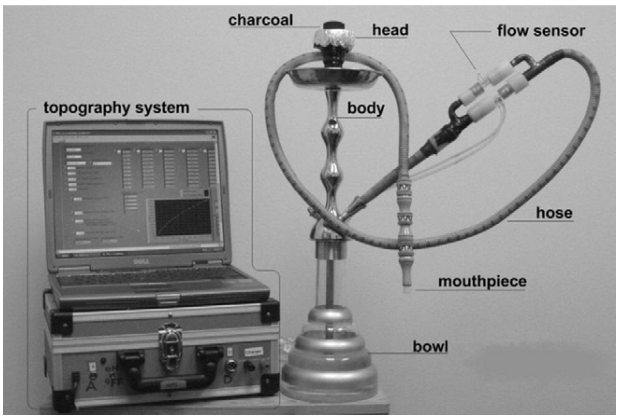

Figure 1. Waterpipe with modified hose assembly and topography measurement hardware. The waterpipe consists of a head in which sweetened and flavored tobacco is placed, a body that holds the head atop a conduit, a bowl that is half filled with water that submerges the bottom of the conduit, and a hose that emerges from the bowl above the waterline and terminates in a mouthpiece. The tobacco in the head is heated with charcoal (often separated from the tobacco by a piece of perforated aluminum foil), and when the user sucks on the mouthpiece, charcoal-heated air passes through the tobacco, and tobacco and charcoal smoke travel through the conduit, water, hose, and mouthpiece and then into the user's mouth and lungs. The hose attached to this waterpipe has been modified by the insertion of a flow sensor that is used to measure puff topography (see text for details).

smoker toxicant exposure, and no controlled, head-to-head comparison of smoker toxicant exposure for waterpipes and cigarettes has been reported. Such a comparison would address the oft-reported perception that, relative to cigarette smoking, waterpipe tobacco smoking presents reduced health risks.[13–15]

Indeed, understanding the relative smoker toxicant exposure associated with waterpipe and cigarette smoking is of great interest: The two have been compared briefly and indirectly in virtually every empirical study in which waterpipe toxicant exposure has been measured.[16–20] However, comparisons of toxicant exposure across different tobacco use methods are more than inherently interesting: The observation that cigarette and smokeless tobacco use are associated with equivalent peak blood nicotine concentration[21] provided support for the use of nicotine replacement medications for treatment of smokeless tobacco users.[22] Perhaps most important, comparing the waterpipe and cigarette toxicant exposure can help physicians and other public health professionals address misperceptions driving the global spread of waterpipe use. Thus, the purpose of this study is to provide the first controlled, direct laboratory comparison of the toxicant exposure associated with waterpipe tobacco and cigarette smoking.

Waterpipe tobacco smokers who also smoked cigarettes participated in two laboratory sessions in which they smoked a waterpipe or a cigarette ad libitum. Outcomes included expired-air CO concentration; carboxyhemoglobin (COHb) and plasma nicotine levels; heart rate; and puff topography. Based on cross-study comparisons,[23] it was hypothesized that, relative to cigarette smoking, waterpipe tobacco smoking would be associated with greater CO and nicotine exposure as well as greater puff number and volume.

Methods

Participants

Thirty-nine participants recruited in 2008–2009 from the Richmond VA community, using advertisements and word of mouth, provided informed consent for this study, which was approved by the Virginia Commonwealth University IRB. Of these 39, two withdrew and two were discontinued because of scheduling difficulties or protocol noncompliance. The blood samples for four of the remaining 35 participants returned results that were not valid, so the final sample consisted of 31 individuals (21 men; 22 Caucasian, three Asian, one African American, and five mixed or other ethnicity). These participants were healthy, aged 18–50 years (M=21.4 years, SD=2.3), and reported at least monthly waterpipe tobacco smoking (M=5.2 uses/month, SD=4.0) and weekly cigarette smoking (M=9.9 cigarettes/day, SD=6.4). Exclusion criteria included self-reported history of chronic health conditions, current pregnancy or breastfeeding, use of tobacco products other than waterpipe or cigarettes, currently attempting to quit smoking, or use of marijuana for more than 5 days of the past 30 (all marijuana use was not excluded because as many as 36% of U.S. waterpipe tobacco smokers may also use marijuana[13]).

Study Design and Procedures

This laboratory study used a two-condition crossover design in which all participants completed two approximately 2-hour sessions that differed by product used (waterpipe or cigarette); condition order was counterbalanced. Pre-session abstinence (≥12 hours) was required before each session. Once abstinence was verified (i.e., by measuring expired-air CO and requiring ≤10 ppm), a catheter was inserted into a forearm vein and the session began with continuous heart-rate recording. Breath and blood were sampled after 30 minutes of heart rate data had been recorded and then session-specific product was administered. For a waterpipe session, a waterpipe with 15 g of tobacco in the foil-covered head was presented and a lit charcoal briquette (sold for waterpipe use) was placed on the perforated foil. Participants were instructed that the waterpipe would be available for 45 minutes (approximate waterpipe smoking–episode duration[24]) and that an additional half briquette could be added on request. For a cigarette session, a lit cigarette was placed into a mouthpiece that was connected to a topography measurement device. In each session, participants were seated comfortably and viewed a video of their choice. Blood was sampled at 5, 15, 30, and 45 minutes after smoking began. Breath was sampled before smoking and at 50 minutes in order to avoid contamination of the sample with smoke that remained in the lung or oral cavity. Payment for completing both sessions was $175. The laboratory was ventilated with exhaust fans, and ambient CO levels (measured for 19 participants) never exceeded 7 ppm

in any session (M=4.2 for waterpipe sessions and 0.4 for cigarette sessions).

Materials

The waterpipe consisted of a chrome body (height=43 cm) screwed into an acrylic base (height=24 cm; volume=1230 mL; www.myasaray.com). Water (870 mL) was poured into the base, submerging about 2.5 cm of the body's conduit. The head (height=7.6 cm; www.hookahcompany.com) was made of glazed ceramic and had five holes in the bottom (each approximately 6 mm in diameter). The leather hose was fitted with puff topography measurement hardware[25] and terminated with a wooden mouthpiece (Figure 1). A circular sheet of aluminum foil (diameter=11.5 cm; www.smoking-hookah.com) separated the quick-lighting waterpipe charcoal briquette (Three Kings, Holland) from the tobacco, after the foil had been perforated with a screen pincher (www.smoking-hookah.com). A sterile plastic tip (www.hookahcompany.com) was added to the mouthpiece for each participant.

Participants smoked their preferred waterpipe tobacco flavor. Fruit flavors were most common (e.g., nine participants chose strawberry, six mango, five apple/double apple). Frequently, participants were unable to name a preferred tobacco brand, so Nakhla (Egypt) was used (n=22). Other brands included Al-Fakher (United Arab Emirates; n=5); Al-Amir (Saudi Arabia; n=2); and Starbuzz (U.S.; n=2; all purchased from www.hookahcompany.com). Using available data for 23 participants,[26] preferred-brand cigarettes yielded, on average, 0.9 mg nicotine (SD=0.2); 12.0 mg CO (SD=2.2); and 11.7 mg tar (SD=2.5).

Outcome Measures

Expired-air CO was assessed with a BreathCO monitor (Vitalograph). The level of COHb was analyzed less than 1 minute after sampling (NPT7 blood gas analyzer, Radiometer America) and then 10 mL of blood was centrifuged, plasma stored at –70°C, and analyzed for nicotine level (limit of quantitation [LOQ][27]=2.0 ng/mL). Heart rate was measured every 20 seconds (Model 506, Criticare Systems, fitted with a reusable finger pulse oximeter sensor).

To measure waterpipe puff topography, a differential pressure flow sensor was integrated into the waterpipe hose.[25] For cigarettes, participants smoked through a mouthpiece orifice that was connected to a pressure transducer (CReSS Lab, Borgwaldt KC). In both cases, previously calibrated software converted digital signals to air flow (milliliters per second) and integrated these data to produce measures of puff volume, number, and interpuff interval (IPI).

Data Preparation and Analyses

Data were analyzed in 2009. For plasma nicotine, results below the LOQ were replaced with the LOQ. Heart-rate data were averaged for 5-minute periods beginning with the 5 minutes preceding product administration. Data were analyzed using a repeated measures ANOVA with two factors: session (waterpipe or cigarette) and time (levels varied by measure). In addition, each session's peak COHb and plasma nicotine level were determined and these data were analyzed using a single-factor (session) repeated measures ANOVA. Topography data were averaged within each session to obtain a single value for puff volume and IPI, and these measures and puff number and total puff volume were analyzed using a single-factor (session) ANOVA (data for two participants were missing; thus n=29 for topography only). Huynh–Feldt corrections were used to account for violations of sphericity, and for comparisons between means, Bonferroni-corrected dependent t tests were conducted.[28]

Results

Of the 31 participants, five chose to use an additional half charcoal briquette during their waterpipe session; the pattern of results was not influenced by these five participants, so their data are included in all analyses described below.

For expired-air CO, statistical analysis revealed a significant condition by time interaction (F[1, 30]=36.9, p<0.001). For cigarette, mean (±SEM) pre-smoking CO level was 5.1±0.5 ppm and increased to 7.8±0.6 after smoking, while for waterpipe, mean pre-smoking CO level was 4.7±0.5 ppm and increased to 28.7±3.5 after smoking (t[30]>6.7, p's<0.001]. The higher post-smoking CO associated with waterpipe tobacco smoking was significant (t[30]=5.8, p<0.001).

The mean COHb data are shown in Figure 2 (top), and analysis revealed a significant condition by time interaction (F[4, 120]=35.6, p<0.001). For cigarette, mean (±SEM) pre-smoking COHb level was 0.95±0.08% and increased to 1.1±0.11% at 5 minutes, 1.2±0.10% at 15 minutes, 1.2±0.10% at 30 minutes, and 1.1±0.08% at 45 minutes (t[30]>4.7, p's<0.001). For waterpipe, mean pre-smoking COHb level was 0.75±0.09% and increased to 1.8±0.21% at 5 minutes, 2.7±0.29% at 15 minutes, 3.6±0.41% at 30 minutes, and 3.9±0.46% at 45 minutes (t[30]>5.1, p's<0.001). The higher COHb associated with waterpipe tobacco smoking relative to cigarette smoking was significant at every post-smoking time point (t[30]>6.7, p's<0.001). Analysis of peak data revealed a significant effect (F[1, 30]=35.0, p<0.001), with a mean peak COHb for cigarette of 1.3±0.10% and for waterpipe of 3.9±0.5%.

The mean plasma nicotine data are shown in Figure 2 (bottom), and analysis revealed a significant condition by time interaction (F[4, 120]=14.5, p<0.001). For cigarette, mean (±SEM) pre-smoking plasma nicotine concentration was 2.1±0.1 ng/mL and increased to 10.0±1.4 ng/mL at 5 minutes, 6.8±0.7 ng/mL at 15 minutes, 5.0±0.6 ng/mL at 30 minutes, and 4.1±0.4 ng/mL at 45 minutes (t[30]>5.1, p's<0.001). For waterpipe, mean pre-smoking plasma nicotine concentration was 2.0±0.2 ng/mL and increased to 6.1±1.1 ng/mL at 5 minutes, 6.4±0.8 ng/mL at 15 minutes, 7.9±1.0 ng/mL at 30 minutes, and 8.5±1.0 ng/mL at 45 minutes (t[30]>3.6, p's<0.001). The higher nicotine level associated with waterpipe tobacco smoking relative to cigarette smoking was significant at 45 minutes (t[30]=4.3, p<0.001). Analysis of peak effect data revealed no significant effect (F[1, 21]=0.07, n.s.),

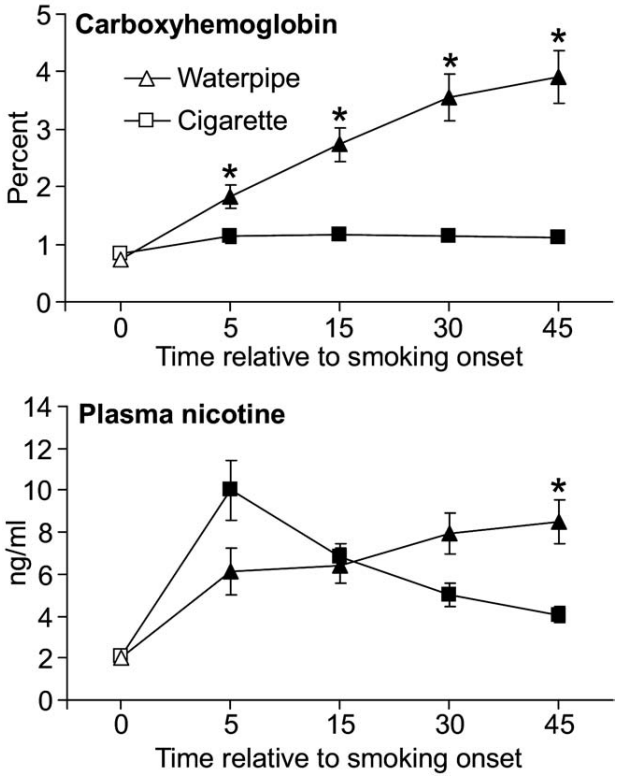

Figure 2. Mean (±1 SEM) carboxyhemoglobin (top panel) and plasma nicotine (bottom panel) data from 31 participants who smoked tobacco using a waterpipe (triangles) or cigarette (squares) in a laboratory session. Although both waterpipe and cigarette smoking were ad libitum, the waterpipe was available for 45 minutes while the cigarette was consumed in approximately 5 minutes. Filled symbols indicate a significant difference from baseline (Time 0), and asterisks (*) indicate a significant difference between conditions at that time point (p's<0.001).

with a mean peak plasma nicotine concentration for cigarette of 10.6±1.4 ng/mL and for waterpipe of 10.2±1.3 ng/mL.

Analysis of heart rate data revealed a significant condition by time interaction (F[9, 261]=24.2, p< 0.001). For cigarette, a significant increase in heart rate was observed when pre-smoking data are compared to the first 5-, 10-, 15-, 20-, 25-, and 35-minute time points, while for waterpipe, a significant increase relative to pre-smoking data was observed for all time points (t[30]> 4.1, p<0.001). For cigarette, mean (±SEM) pre-smoking heart rate was 68.9±1.8 beats per minute (bpm) and was 81.2±2.2 bpm at 5 minutes, 85.7±2.1 bpm at 10 minutes, 72.2±1.8 bpm at 30 minutes, and 69.6±1.6 bpm at 45 minutes. For waterpipe, mean pre-smoking heart rate was 69.2±1.6 bpm and was 73.3±1.6 bpm at 5 minutes, 80.0±2.2 bpm at 10 minutes, 76.6±1.9 bpm at 30 minutes, and 75.5±1.8 bpm at 45 minutes. The greater heart rate associated with cigarette smoking relative to waterpipe smoking was significant at 5 minutes, while the reverse relationship was true at 35 and 45 minutes (t[30]=3.9, p's<0.001).

Table 1 shows the means and SDs for each puff topography measure and, as shown in the table, significant differences were observed across conditions for each measure (F[1, 28]>68.4, p's<0.001). Relative to a cigarette, waterpipe was associated with 4.7 times the number of puffs and 48.6 times the amount of smoke. Each puff from the waterpipe involved 12.0 times the smoke of a cigarette puff.

Discussion

Relative to a single cigarette, a single waterpipe-use episode is associated with similar peak plasma nicotine levels and three times greater peak COHb levels. The first 5 minutes of waterpipe smoking produced more than four times the increase in COHb as smoking an entire cigarette (i.e., first-5-minute increase of 145% for COHb vs 34% for a cigarette). The observation that heart rate changes mirrored blood nicotine levels supports the notion that, for waterpipes and cigarettes, nicotine doses were physiologically active. Finally, puff topography data suggest that, relative to a cigarette, a 45-minute waterpipe tobacco smoking–episode generates more than 40 times the smoke volume. Previous analyses of waterpipe smoke demonstrate that, in addition to CO and nicotine, it contains carcinogenic polycyclic aromatic hydrocarbons,[12] pulmonary disease–causing volatile aldehydes,[29] and a variety of heavy metals,[10] and, as indicated by ambient CO elevation in this study, at least some of these toxicants are also present in environmental tobacco smoke produced by the waterpipe.[30] Taken together, these data provide no support for the notion that waterpipe tobacco smoke is less lethal than cigarette smoke. Instead, despite the lack of waterpipe-specific epidemiologic studies of health risk, the weight of the evidence provided here and in previous reports[1,10,12,23,29] suggests that waterpipe tobacco smoking is likely associated with many of the same tobacco-caused diseases as cigarette smoking, including cancer, cardiovascular and lung disease, and nicotine dependence.

Although peak nicotine concentrations are similar for cigarette and waterpipe conditions, the relatively

Table 1. Puff topography for cigarette or waterpipe

	Cigarette	Waterpipe	
Topography measure	**M (SD)**	**M (SD)**	***p*-value[a]**
Puff number	15.2 (5.5)	71.7 (39.5)	<0.001
Total volume (L)	1.0 (0.5)	48.6 (26.2)	<0.001
Mean puff volume (mL)	67.9 (26.2)	817.6 (484.2)	<0.001
IPI (seconds)	24.5 (10.7)	42.9 (21.0)	<0.001

Note: n=29; two participants had missing data
[a]F(1, 28)>68.4
IPI, interpuff interval

long duration of a waterpipe-use episode (45 minutes in this study)[10,13,31] results in considerably greater effective nicotine exposure. Using a single-compartment pharmacokinetics model with linear clearance kinetics[32] and a nicotine clearance constant of 0.0333 min^{-1} obtained by fitting an exponential decay curve to the average nicotine concentrations at 5, 15, 30, and 45 minutes post–cigarette initiation (R^2=0.98), the nicotine area under the curve (AUC) observed in this study was 243 ng/mL-minute for the cigarette and 418 ng/mL-minute for the waterpipe. Thus, relative to a cigarette, participants in this study were exposed to 1.7 times the nicotine dose when they were smoking tobacco in a waterpipe. This observation is consistent with cross-study comparisons that used machines to generate waterpipe and cigarette smoke and showed that the smoke generated during a typical waterpipe smoking episode contains about 1.7 times the nicotine as smoke generated by a cigarette.[23]

Despite the fact that this study has some important limitations (e.g., sample of waterpipe tobacco smokers who also smoke cigarettes, laboratory setting), many of the waterpipe-related results observed here are consistent with previous reports. For example, the expired-air CO increase observed after waterpipe tobacco smoking in this study (M=23.9 ppm) is similar to that observed in waterpipe tobacco smokers in California (M=32 ppm)[18]; Aleppo, Syria (M=31 ppm)[31]; and Beirut, Lebanon (M=22 ppm),[17] although lesser increases have been reported (i.e., 14 ppm).[20] Heart rate increases that are maintained throughout a 45-minute waterpipe tobacco smoking session have also been observed.[20] The waterpipe puff topography data differ from previous reports: The mean puff volume of 0.8 L is greater than the approximately 0.5 L reported previously,[25,31] and the 43-second IPI is greater than the previously reported 13–16 seconds.[25,31] These cross-study differences may reflect differences in study populations: Smokers in Lebanon and Syria may be more experienced (e.g., ~30 uses/month),[31] leading to smaller but more frequent puffs. Interestingly, the cigarette puff topography parameters are also substantially greater than those reported elsewhere, even when data were collected under similar abstinence and laboratory conditions (e.g., M puff number=11 puffs, M puff volume=59 mL).[33] One potential explanation for the greater puff number and volume observed in participants who smoke both cigarettes and waterpipe is that the experience of inhaling more smoke when using a waterpipe generalizes to subsequent cigarette smoking. Finally, only one other laboratory study has measured waterpipe-induced plasma nicotine levels, and even greater nicotine exposure was observed (i.e., an increase of 59 ng/mL).[19] Without exception, every controlled study of waterpipe-user toxicant exposure and/or puff topography supports the same conclusion: Waterpipe tobacco smoking involves considerable CO, nicotine, and smoke exposure.

There is little doubt that waterpipe tobacco smoking is an international phenomenon driven, at least in part, by the perception that this method of tobacco smoking is less lethal than cigarette smoking.[13–15] Addressing this perception conclusively may require large-scale, multiyear epidemiologic studies like those used to investigate the health effects of so-called low-yield cigarettes.[34] The results of those waterpipe-focused epidemiologic studies may be available some years in the future, but today's challenge is to reduce current waterpipe tobacco smoking and prevent its further spread. In this context, the present results may be critical: They can be used by physicians on an individual level and public health authorities on a population level to address misperceptions regarding the relative toxicant exposure associated with cigarette and waterpipe tobacco smoking.

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