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A review of air quality, biological indicators and health effects of second-hand waterpipe smoke exposure

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ABSTRACT

Objective There has been a rapid increase in the use of waterpipe tobacco and non-tobacco based shisha in many countries. Understanding the impact and effects of second-hand smoke (SHS) from cigarette was a crucial factor in reducing cigarette use, leading to clean indoor air laws and smoking bans. This article reviews what is known about the effects of SHS exposure from waterpipes.

Data sources We used PubMed and EMBASE to review the literature. Articles were grouped into quantitative measures of air quality and biological markers, health effects, exposure across different settings, different types of shisha and use in different countries.

Study selection Criteria for study selection were based on the key words related to SHS: waterpipe, hookah, shisha and third-hand smoke.

Data extraction Independent extraction with two reviewers was performed with inclusion criteria applied to articles on SHS and waterpipe/hookah/shisha. We excluded articles related to pregnancy or prenatal exposure to SHS, animal studies, and non-specific source of exposure as well as articles not written in English.

Data synthesis A primary literature search yielded 54 articles, of which only 11 were included based on relevance to SHS from a waterpipe/hookah/shisha.

Conclusions The negative health consequences of second-hand waterpipe exposure have major implications for clean indoor air laws and for occupational safety. There exists an urgent need for public health campaigns about the effects on children and household members from smoking waterpipe at home, and for further development and implementation of regulations to protect the health of the public from this rapidly emerging threat.

INTRODUCTION

While cigarette use has decreased dramatically in recent years, there has been a marked increase in adolescent and young adult use of alternative, non-cigarette tobacco products. The total consumption of cigarettes in the USA decreased by 33% between 2000 and 2011¹; however, estimations from this same time period show a 123% increase in the consumption of alternative tobacco products, including hookahs (waterpipes), cigarillos, cigars, bidis, kreteks and smokeless tobacco (snuff, dip, snus and chewing tobacco).¹

Inhalation of second-hand smoke (SHS) by non-smokers has been associated with multiple diseases in paediatric and adult populations. Such evidence is especially troubling given the 2006 report by the

US Department of Health and Human Services, which estimated that 60% of US non-smokers are exposed to SHS.² Exposure occurs through several distinct routes: sidestream smoke, mainstream smoke, or smoke that has permeated the air of the surrounding environment. Sidestream smoke is the smoke discharged from the lit end of a burnt tobacco product; mainstream smoke is the smoke that is inhaled by a smoker and subsequently exhaled into the environment during a period of active smoking.³ Another route of exposure by non-smokers is third-hand smoke (THS), which is defined as the residual matter from tobacco smoke that collects on surfaces and in dust.⁴ While SHS and THS have historically been associated with cigarette smoke, there has recently been an alarming rise in alternative non-cigarette tobacco use, raising the important question of whether these products also generate harmful SHS and THS.

Hookah (also called waterpipe, nargile or hubble-bubble) is perceived to be safer and less addictive than cigarettes, despite growing evidence that hookah smoke is potentially more harmful than cigarette smoke.^{5–8} This is worrisome given that the 2011 National Youth Tobacco Survey (NYTS) found a 7.3% prevalence of waterpipe use among adolescents in the USA (roughly 2 million adolescents).⁹ This study also showed that 53.1% of adolescents living in a home with a hookah user reported trying hookah. Another recently published study using a nationally representative sample from Monitoring the Future showed that adolescents from more highly educated families and who had more discretionary money were more likely to use hookahs.¹⁰ A study of pregnant women in Jordan showed that the household accounts for nearly 49% of second-hand and third-hand waterpipe exposure, which highlights the need for additional research on home exposure and populations that may be at particular risk of exposure within the home, such as children.¹¹

METHODS

We conducted a primary literature search in two separate databases; PubMed and EMBASE. We used the following search terms:

passive smoking, second hand smoke, second hand smoker, second hand smokers, second-hand smoke, third hand smoke, waterpipe, waterpipes, water-pipe, water-pipes, hubble-bubble, hookah nargile, shisha, qalyan.

We combined the list of articles found from the two databases. Two reviewers went through the title and abstract of each article for relevance. We

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included articles with original research on SHS or THS from waterpipes (figure 1). We excluded all review articles and original research articles that were written in languages other than English, were related to waterpipe use and pregnancy, involved animal models, studied SHS from a non-specific sources, or were unrelated.

The small number of articles that we found precluded conducting a meta-analysis. Instead, we simply present them as a narrative review.

RESULTS

We found a total of 54 articles that were manually reviewed by two researchers to yield a total of 11 relevant articles. The reasons for excluding articles were: not published in the English language (n=3); focused on pregnancy and waterpipes (n=4); had a non-specific source of SHS either from cigarette, waterpipe, or other tobacco sources (n=5); were unrelated to the topic (n=26); review articles (n=3); non-human studies (n=1) and duplicate articles (n=1). See figure 1 for the search strategy algorithm. We have summarised the articles that were included in the narrative review in table 1.

Venues where individuals are exposed to waterpipe smoke

We found one study that assessed exposure to waterpipe smoke and cigarette smoke among 387 people in Iran.¹² The most common places that people were exposed to hookah smoke were in the home (93.4%), coffee shops (17.1%) and restaurants (11.5%). In this same article from Iran, people were exposed to environmental cigarette smoke more often in public vehicles (52.2%) and the home (31.3%).

Measures of SHS from waterpipes: studies of air quality and biological absorption

Air quality

The composition of waterpipe smoke has been shown to include a number of potentially harmful toxins and chemicals.

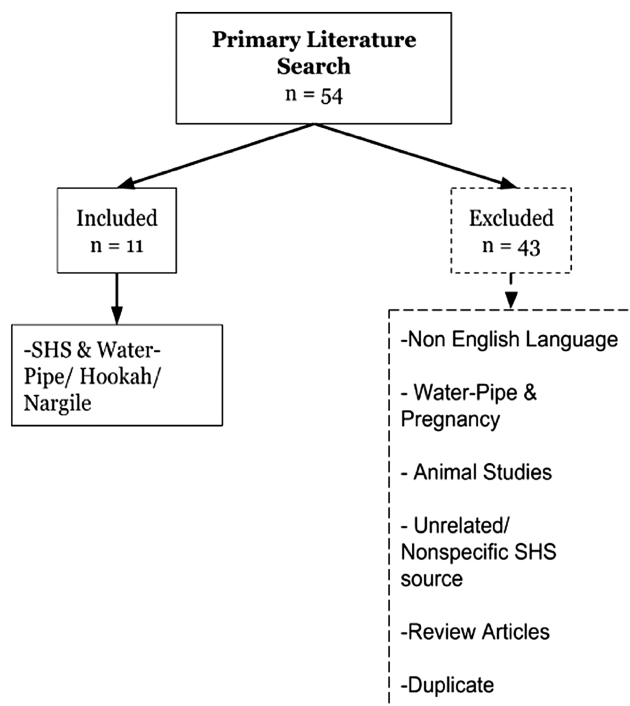


Figure 1 Search strategy algorithm (SHS, second-hand smoke).

However, there has been a paucity of studies to date, with many of these studies measuring air quality only in hookah lounges. There is limited data on ambient air quality in other settings and only one study identified in this review that measured air quality specifically in the home.

Particulate matter

We found only three articles in the USA that assessed levels of particulate matter (PM) resulting from waterpipe smoke. Air quality in the USA is defined by the Environmental Protection Agency (EPA) based on the Air Quality Index (AQI) that is dependent on the peak PM concentration ($PM_{2.5}$ ($\mu\text{g}/\text{m}^3$)). This index ranges from a rating of good (0–50) to hazardous (301–500); all higher readings surpassing 500 are still considered to be hazardous.¹³ In Oregon, Fiala *et al*¹⁴ analysed the air quality in 10 hookah lounges, all of which were found to have a minimum index rating of unhealthy (AQI 151–200), with 2 reaching the hazardous level. In Virginia, Cobb *et al*¹⁵ compared SHS among a variety of venues with differing smoking rules. Of great concern, the $PM_{2.5}$ concentration was greater in the waterpipe cafes (mean of $374 \mu\text{g}/\text{m}^3$, AQI hazardous) compared with establishments where cigarette smoking, but not use of waterpipes, was occurring (mean of $119 \mu\text{g}/\text{m}^3$, AQI unhealthy). Furthermore, the non-smoking sections of the waterpipe cafe were found to have a similar mean ($123 \mu\text{g}/\text{m}^3$, AQI unhealthy) to restaurants where cigarettes are smoked.

Two studies from other countries have also analysed levels of PM, as well as other indicators of air quality such as carbon monoxide (CO) and nicotine. In Toronto, Canada, Zhang *et al*¹⁶ measured the ambient air in indoor and outdoor waterpipe venues. Indoor venues were shown to have hazardous levels of $PM_{2.5}$ with a significant mean of $1419.4 \mu\text{g}/\text{m}^3$, about 69 times higher than that of ambient air, whereas outdoor venues had poor levels of $PM_{2.5}$ with a significant mean of $80.5 \mu\text{g}/\text{m}^3$, still above the EPA ‘good’ level of 0–59. A study conducted in Pakistan by Zaidi *et al*¹⁷ collected data from 13 hookah venues and found an average $PM_{2.5}$ of $1745 \mu\text{g}/\text{m}^3$.

Potentially dangerous toxic exposures other than PM

Another way of approximating air quality is to look at sidestream smoke. Although it is likely that sidestream smoke is more concentrated than ambient air in outdoor spaces, it may provide valuable information on additional features to consider for future ambient air studies. A study by Daher *et al*⁷ compared the sidestream emissions from a single waterpipe session to that of one cigarette. The authors found that the sidestream smoke of waterpipe smoke had nearly four times the carcinogenic polycyclic aromatic hydrocarbon (PAH), four times the volatile aldehydes and 30 times the CO of one cigarette. With regard to the biological agents studied, Markowicz *et al*¹⁸ discovered the presence of bacterial lipopolysaccharides (LPS) in SHS during a waterpipe smoking session.

A study by Hammal *et al*¹⁹ analysed the mainstream and sidestream smoke from three products of herbal shisha and found that mainstream and sidestream smoke emissions from herbal shisha contain carcinogens equal to or greater than those found in tobacco products. The results showed significant levels of aromatic hydrocarbons, CO, $PM_{2.5}$ and trace metals.

Nicotine in ambient air and metabolites of nicotine are often thought of merely as measures of exposure. However, an extensive body of literature demonstrates the profound negative health consequences of nicotine exposure, such as its potential for addiction to itself and other agents and its cardiovascular effects.²⁰ A recent study by Kassem *et al*²¹ found that nicotine

Table 1 Articles obtained from the literature search

Lead author	Year	Country	Type and number of subjects (or target places)	Study design	Outcomes measured	Summary	Main findings	Exclusion of other sources of second-hand smoke
Cobb <i>et al</i> ¹⁵	2013	USA	28 venues in Virginia (17 waterpipe cafes, 5 restaurants permitting cigarette smoking and 6 smoke-free restaurants (5 with valid data))	Observational	PM with a 2.5 µm aerodynamic diameter or smaller (PM _{2.5})	Waterpipe café smoking rooms have a hazardous level of PM _{2.5} that could be potentially harmful to customers and workers	PM _{2.5} was greater in waterpipe café smoking rooms (374 µg/m ³ , n=17) compared with waterpipe café non-smoking rooms, cigarette smoking-permitted restaurant smoking rooms, cigarette smoking-permitted restaurant non-smoking rooms, and smoke-free restaurants	Measurements began 5 min prior to entering the venue and ended 5 min after exiting each venue to compare outdoor ambient air to the air inside the venue
Daher <i>et al</i> ⁷	2010	Lebanon	4 repeated waterpipe-smoking sessions and 4 repeated cigarette trials	Observational	Sidestream smoke from waterpipes or cigarettes for ultrafine particles, carcinogenic polyaromatic hydrocarbons, volatile aldehydes, and CO	Second-hand waterpipe smoke emits significant harmful substances	Sidestream waterpipe smoke had nearly 4 times the carcinogenic PAH, 4 times the volatile aldehydes and 30 times the CO of 1 cigarette	Smoking-machine and environmental chamber approach allowed for repeated measurements under controlled conditions and few confounding variables
Fiala <i>et al</i> ¹⁴	2012	USA	10 indoor hookah lounges in Oregon	Observational	PM smaller than 2.5 µm in diameter	Air quality in hookah lounges in Oregon ranges from unhealthy to hazardous	2 hookah lounges had peak PM _{2.5} measurements in the hazardous EPI air quality category, 4 were very unhealthy, and 4 were unhealthy. None had good air quality	Measurements began prior to entering the venues and ended after exiting the venues to compare the outdoor ambient air to the air in the hookah lounges
Fini <i>et al</i> ¹²	2013	Iran	387 total persons (172 male and 215 female)	Observational	Demographic characteristics and questions related to environmental tobacco smoke exposure	A large proportion of citizens of Bandar Abbas city are exposed to environmental tobacco smoke	The most common places that people were exposed to hookah smoke were in the home (93.4%), coffee shops (17.1%) and restaurants (11.5%). People were exposed to environmental cigarette smoke in public vehicles (52.2%) and the home (31.3%)	NA
Hammal <i>et al</i> ¹⁹	2013	Canada	3 replicates of each of the 3 brands were analysed. 6 randomly selected waterpipe cafes were visited	Observational	Chemical constituents of tobacco-free products used in waterpipes, waterpipe emission under controlled conditions, and air quality markers in waterpipe cafes	Second-hand smoke from herbal shisha contains carcinogens equal to or greater than that found in cigarettes and may be hazardous	Second-hand waterpipe smoke had significant levels of aromatic hydrocarbons, CO, PM _{2.5} and trace metals	Measurements taken outdoors before and after the visit for comparison
Kassem <i>et al</i> ²¹	2014	USA	24 homes were visited 3 times during a 7-day period	Observational	Levels of indoor air and surface nicotine, child uptake of nicotine, the carcinogen NNK, and the toxicant acrolein by measuring corresponding metabolites cotinine, NNAL and NNAL-glucuronides and 3-HPMA	Children living in homes of hookah smokers are exposed to nicotine, the carcinogen NNK and the toxicant acrolein, which pose a threat to long-term health	Compared with homes of non-smokers, children living in homes of daily or weekly/monthly hookah smokers had significantly elevated levels of cotinine and NNAL, with children of daily smokers also having significantly elevated 3-HPMA	2 air samples were collected with passive diffusion monitor badges in the living room and child's bedroom. A blank non-analysed badge was placed in a third room
Markowicz <i>et al</i> ¹⁸	2014	Sweden	Filters from 10 replicate sessions of waterpipe smoking	Observational	Microbial compounds in waterpipe smoke	Waterpipe smoke creates a bioaerosol similarly to cigarette smoke	In a 1–2 h session, second-hand smoke from waterpipes produced a concentration of 2.8 pmol/m ³ of LPS. Ergosterol was not detected. This is comparable to 22.2 pmol/m ³ of LPS and 87.5 ng/m ³ of ergosterol from smoking 5 cigarettes	NA
Tamim <i>et al</i> ²²	2003	Lebanon	625 students from 5 different private schools	Observational	Information on demographic, in-home smoking, and students' respiratory tract illnesses (cough, wheezing, runny nose, or nasal congestion)	Children exposed to second-hand waterpipe smoke may develop respiratory problems	22.6% (12/53) had wheezing or nasal congestion, 11.3% (6/53) had just wheezing, and 15.1% (8/53) had just nasal congestion	NA

Continued

Table 1 Continued

Lead author	Year	Country	Type and number of subjects (or target places)	Study design	Outcomes measured	Summary	Main findings	Exclusion of other sources of second-hand smoke
Zaidi <i>et al</i> ¹⁷	2011	Pakistan	39 indoor venues (13 shisha smoking, 13 cigarette smoking, and 13 non-smoking)	Observational	Mean concentration of PM _{2.5}	Air quality at shisha smoking venues had hazardous air quality	Shisha smoking venues had an average PM _{2.5} of 1745 µg/m ³	Venues with other sources of indoor air pollution and non-air-conditioned venues exposed to outdoor pollution were excluded. Samples were obtained before entering the venues to calibrate the device
Zeidan <i>et al</i> ²³	2014	Lebanon	147 people surveyed	Observational	Questionnaires on sociodemographic characteristics, respiratory symptoms and exposure to second-hand smoke. Exhaled CO levels	Second-hand waterpipe smoke may cause respiratory symptoms in non-smokers	Of the 147 surveyed, 48 were exposed only to second-hand waterpipe smoke. 58% reported a chronic cough	Measurements of expired-air CO were calibrated with local environmental CO concentration
Zhang <i>et al</i> ¹⁶	2013	Canada	Indoor (n=12) and outdoor (n=5) air quality was assessed in Toronto, Canada waterpipe cafes	Observational	Air nicotine, fine PM less than 2.5 µm in diameter, and ambient CO	Air quality of waterpipe cafes is a health hazard. Waterpipe smoking should be eliminated from indoor and outdoor hospitality venues	Indoor values were 1419 µg/m ³ for PM _{2.5} , 17.7 ppm for ambient CO, and 3.3 µg/m ³ for air nicotine. Outdoor values were 80.5 µg/m ³ for PM _{2.5} , 0.5 ppm for ambient CO, and 0.6 µg/m ³ for air nicotine	Measurements taken as far as possible from kitchen areas and open windows to reduce contamination. Background readings obtained outdoors in areas without nearby smokers

3-HPMA, 3-hydroxypropylmercapturic acid; CO, carbon monoxide; EPI, Environmental Performance Index; LPS, lipopolysaccharides; NA, not applicable; NNAL, 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanol; NNK, 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanol; PM, particulate matter.

levels in indoor air collected from the homes of daily hookah smokers were significantly higher than in the air collected from the homes of non-smokers.

Biological indicators

In contrast to studies conducted in hookah bars, we have found only one study to date that has explored hookah smoke in homes. The previously mentioned study by Kassem *et al*²¹ explored the effects of SHS on children under 5 years of age in the homes of hookah users. The inhaled levels of the following potentially harmful chemicals found in SHS were measured in urine: nicotine, acrolein, and 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanol (NNK). These chemicals were measured according to their metabolites cotinine, 3-hydroxypropylmercapturic acid (3-HPMA) and 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanol (NNAL), respectively. Compared with homes of non-smokers, children living in homes of daily or weekly/monthly hookah smokers had significantly elevated levels of cotinine and NNAL, with children of daily smokers also having significantly elevated 3-HPMA.

Health effects of SHS exposure from waterpipes

Of course, the importance of exposure is the potential for untoward health effects. However, to date, the studies have been limited to acute effects, where as we know from a century of research on cigarettes that the most dangerous effects are long term. We found two studies from Beirut, Lebanon that reported on health effects of SHS exposure from waterpipe use. Tamim *et al*²² surveyed 625 students (mean age of 13 years) for details of their exposure and respiratory symptoms. They found that 8.5% (53 students) reported being exposed to SHS from waterpipe use at home due to parental use. Of the respiratory symptoms surveyed, 22.6% (12/53) had wheezing or nasal congestion when exposed to SHS from waterpipe use at home, compared with 11.2% (21/187) who had no exposure to any SHS at home; 11.3% (6/53) vs 5.3% (10/187) had just wheezing; and 15.1% (8/53) vs 7.5% (14/187) had just a nasal congestion. Zeidan *et al*²³ surveyed 147 non-smokers (age range 18–35 years) on their demographics, exposure to SHS from either a waterpipe or cigarettes, and respiratory symptoms. Of the 147 respondents, 48 were exposed to only waterpipe SHS, and a majority of these people (58% or 29/48) reported having a chronic cough. This finding is in comparison to 49 of the 147 who had no exposure to SHS, with only 16.3% of people with a chronic cough.

DISCUSSION

We found that SHS from waterpipes results in exposure to hazardous levels of PM according to the EPA's AQI, as well as carcinogenic PAH, CO, nicotine and bacterial LPS. A recent study in New York City by Zhou *et al*²⁴ (published by our research team after the original literature search) found that overall levels of indoor air pollution increased with rising numbers of active hookahs smoked and that the mean PM_{2.5} level was 694 µg/m³ (AQI hazardous). This same study found a substantial number of potentially toxic exposures that were identified from air samples collected in hookah bars, such as CO, black carbon, elemental carbon, organic carbon, and nicotine, in addition to fine PM and total gravimetric PM. Furthermore, children living in the homes of hookah smokers had elevated levels of cotinine, NNAL and 3-HPMA depending on frequency of use. We did not find any studies reporting on morbidity or mortality directly attributable to SHS or THS from hookah use.

As noted, there is evidence indicating that active waterpipe smoking is not as harmless as was previously believed.^{5–7}

Furthermore, the cancer risk profile may be different in waterpipe-exposed and cigarette-exposed populations due to production of different carcinogens.²⁵ The documented health effects of SHS from cigarettes have had a profound impact on public perception of smoking as well as the passage of policies to protect non-smokers. SHS causes lung cancer and coronary artery disease in adults,^{2 26} as well as sudden infant death syndrome (SIDS), recurrent ear infections and asthma exacerbations, and it is also associated with numerous other health problems in the paediatric population.² According to the Centers for Disease Control and Prevention (CDC), in 2000, 80% of adults recognised that SHS from cigarettes was not only harmful but they also believed that non-smokers should be protected in the workplace from such exposure.² Comparable awareness and beliefs regarding hookah-related SHS are currently woefully lacking.

There is limited literature to date focusing on the impact of SHS exposure from waterpipe use on non-smokers. Further environmental measures of carcinogens and toxins are needed in homes of users as well as in venues that allow hookah use. Thus far, concentrations of CO, thiocyanate or nicotine have been proposed as indirect markers to measure SHS emitted from waterpipes. As described above, a study in 2014 of 24 households with hookah-only smokers or non-smokers found higher air nicotine levels in the homes of hookah-only smokers compared with the homes of non-smokers.²¹ Similarly, indoor environments where waterpipe was smoked had higher pollutant levels. To date, many studies have found increased pollutant levels in indoor environments where waterpipes are smoked.^{7 27 28} For example, sidestream smoke analysis showed that a single session of waterpipe use was associated with four times the carcinogenic PAH, four times the volatile aldehydes and 30 times the CO when compared with one cigarette.⁷ Additional studies are needed to further elucidate the health risk for non-smokers in close proximity to waterpipe smoke.

A number of policies currently exist that aim to control environmental tobacco exposure. These policies include, but are not limited to, smoke-free environments, the regulated sale of tobacco products and tobacco-related advertising as well as restricted sales of tobacco products to minors.²⁹ In addition, increased taxation has a marked effect on cigarette smoking. The WHO Framework Convention on Tobacco Control (FCTC), which was established in 2003 in response to the global tobacco epidemic, included many of these policy initiatives. However, few pieces of waterpipe-specific regulations were included in the FCTC, and therefore waterpipe use remains largely unregulated.^{29 30} According to the American Lung Association, it is imperative to address the health risks to active and passive smokers secondary to waterpipe, especially considering that smoke-free laws often exempt hookah bars from regulation.³⁰ As an example, the USA does not currently have federal tobacco control policies that limit waterpipe access by minors or require visible warning labels on waterpipe products. This lack of regulation may perhaps lead users to believe that waterpipe smoking is less addictive and harmful to their health.²⁹

Clearly, much more research is urgently needed to inform efforts to implement national regulations. It should focus on acute effects (such as on cardiopulmonary or inflammatory changes), chronic effects (such as cancers and long-term cardiac and pulmonary problems), and the potentially unique effects on children. On the basis of data that already exist, we believe that SHS from hookah smoking poses a threat comparable to or even greater than that emanating from cigarette smoking. New

policies and legislation should be implemented to protect people from the harmful effects of SHS from waterpipes.

What this paper adds

- ▶ The recognition of this epidemic is recent, and consequently our knowledge is limited.
- ▶ To date, studies have been able to demonstrate that air in places where hookah is smoked contains high levels of dangerous compounds and that people absorb harmful substances from second-hand waterpipe smoke.
- ▶ The few existing studies suggest negative acute effects on people's health from exposure to second-hand waterpipe smoke.

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