

RITC Monograph Series NO. 2

**Waterpipe  
Tobacco Smoking**  
**Building the Evidence Base**

PART 1: THE SMOKE CHEMISTRY

INTERNATIONAL DEVELOPMENT RESEARCH CENTRE

CENTRE DE RECHERCHES POUR LE DÉVELOPPEMENT INTERNATIONAL

IDRC  CRDI

Canada

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RITC Monograph Series NO. 2

# Waterpipe Tobacco Smoking

**Building the Evidence Base**

**PART 1: THE SMOKE CHEMISTRY**

IDRC  CRDI



## ***Acknowledgements***

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# PREFACE

While the exact history of the waterpipe is unknown, “indigenous people of the Americas, Africa and Asia” have used it for many hundreds of years in some form or another (Shihadeh and Eissenberg, 2005). These authors argue that, for centuries, the waterpipe was seen as a form of “harm reduction” for tobacco users because of the filtering action of the water.

Similar unsubstantiated assumptions about the relative safety of this form of tobacco use may now be playing a role in the waterpipe's recent growing popularity - particularly in a climate of heightened awareness of the negative health impacts of cigarette smoking. (Other likely factors include the very social nature of the activity and the relatively recent innovation of flavouring the tobacco to produce an enticing sweet smell.) Studies on the prevalence, however, are hard to come by but the few that could be found suggest that in countries such as Kuwait, Egypt, Syria and Lebanon, 20-70% of the population has ever smoked the waterpipe and 22-43% currently smokes and that the numbers are substantial among adolescents and young adults (Shihadeh and Eissenberg, 2005). While the highest rates of smoking waterpipe are in the Middle East, North Africa and South East Asia (WHO 2005), waterpipe use now appears to be spreading to Europe, North America and parts of Latin America. One author, for example, estimates that between 200 and 300 “hookah bars” have opened up in the United States since 2001 alone (Loten 2005).

Measuring the increase in waterpipe use has proven to be a bit of a challenge as very few surveys were conducted prior to 1990 and the few that have happened since then have, in the majority, focused on Lebanese students only (Shihadeh and Eissenberg, 2005). These studies suggest that the prevalence of waterpipe use is increasing rapidly among that population (Tamin et al, 2003, Chaya et al, in press, Shediaz-Rizkallah et al, 2001). A Syrian study, which attempted to look at age of initiation, shows that “across all age groups, most waterpipe initiation occurred during the nineties, implicating this decade as the waterpipe epidemic's beginning, at least in this Syrian city [Aleppo]” (Shihadeh and Eissenberg 2005 referring to Maziak et al, 2004).

Concerned by this rapidly growing prevalence and the dearth of research on waterpipe smoking, a multidisciplinary team of researchers at the American University of Beirut (AUB) approached the Research for International Tobacco Control (RITC) program of the International Development Research Centre (IDRC) for funding to undertake a comprehensive research initiative on the subject. The first phase of the project was initiated in 2002 with the objectives of analyzing the interrelationship of political, economic and social processes (i.e. the political economy) in Lebanon that sustains such a high rate of tobacco use (particularly waterpipe use), assessing the health implications and measuring the health effects and smoke toxicants.

It was clear to the AUB researchers that waterpipe smoking differed from cigarette smoking in a number of important ways: 1) as a result of the tobacco being heated by charcoal, smokers inhale combustion products both from the charcoal and the tobacco smoke and possibly products from the foil as well; 2) as the smoke passes through the water, it is cooled and thus appears smoother, cooler and easier to inhale; and 3) waterpipe smokers inhale in a single puff the volume of smoke approximately equivalent to that inhaled for an entire cigarette. What this meant as far as the nature of the smoke was far less clear and thus one of the key concerns of the AUB group was to better understand the nature of the waterpipe smoke. This monograph, therefore, provides state-of-the-art information both on the smoke toxicants and methods for measuring them, and is the first volume to be published coming out of this project. The key findings of these recent studies, as summarized by Shihadeh and Eissenberg, include the following:

- *“Tar”, nicotine, and tobacco consumed in a single session depends strongly on the puffing regimen and coal application, with more intense smoking regimens resulting in greater quantities.*
- *The water bowl decreases the quantity of nicotine several-fold, but has negligible effect on the “tar” yields. This is consistent with the fact that nicotine is semi-volatile and is soluble in water, meaning that it can be readily stripped from the aerosol particles as they pass through the water. [Despite that, a large quantity of nicotine still makes it to the waterpipe mouthpiece].*
- *Relative to the yields of a single cigarette, many times the CO, “tar”, and PAH [polycyclic aromatic hydrocarbons] are produced by a single narghile [waterpipe] smoking session.*
- *The average CO:nicotine ratio of narghile smoke*

*is approximately 50:1 compared to approximately 16:1 for cigarettes, meaning that if smokers titrate for nicotine, narghile smokers using quick-light charcoal will be exposed to much greater quantities of CO.*

- *Similarly, chrysene:nicotine ratios are 15 to 20 times greater for narghile smoke than for cigarette smoke. Chrysene is a tumor initiator.*
- *While the yield of PAHs in a single narghile session exceeds by several times that of a single cigarette..., the concentration of PAHs in narghile “tar” is lower. That is, 1 mg of narghile “tar” does not ‘equal’ 1 mg of cigarette “tar”. This is fortunate for narghile smokers, because a single smoking session produces as much FTC [US Federal Trade Commission] “tar” as 30 to 800 cigarettes.*
- *Peak temperatures measured just under the coal were circa 450 °C, which indicated that the smoke originating from the tobacco should be skewed towards products of simple distillation rather than pyrolysis or combustion (The same is not true for the charcoal, which may experience significantly higher peak temperatures in local reaction fronts.)*
- *The particulate phase is approximately 25-40% water by mass.*
- *By comparing the normal case to cases where charcoal alone is smoked and where tobacco is smoked using an electrical heater in place of the charcoal, it was deduced that the charcoal accounts for almost all of the CO yield under normal smoking conditions.*
- *Extremely high yields of heavy metals were observed..., though data was only obtained for two experiments and should be taken as preliminary.*



What the papers also show is that it is critical to understand the very specific smoking topography of waterpipe smoking (i.e. how it is smoked in terms of number of puffs, puff volume, duration, etc.) and that these need to inform the smoking protocol used to program a smoking machine.

It should be emphasized, though, that these documents, presented here, are **works in progress**. Much still needs to be done to develop standard methods for testing waterpipe. As the authors make clear, they have only looked at one type of tobacco and one charcoal. They have only used one size of waterpipe and one hose length and hose material. Furthermore, as they clearly recognize, they have only scratched the surface in terms of the chemicals investigated having started with those that are known to cause diseases in cigarette smokers. There may be unique risks involved with waterpipes that have yet to be investigated.

This monograph also contains the Shihadeh and Eissenberg report *Tobacco smoking using a waterpipe: product, prevalence, chemistry/toxicology, pharmacological effects, and health hazards* commissioned by The WHO Study Group on Tobacco Product Regulation (TobReg). Based, in part, on the RITC-funded work at AUB, this paper played a significant role in TobReg's decision to issue a Scientific Advisory Note on Waterpipe Smoking. The Advisory Note is reproduced in the last section of this monograph.

A subsequent monograph will report on remaining research results of Phase I of the IDRC-funded AUB project, which focused on population knowledge, attitudes and practices, and the assessment of the policy environment. It will include articles on knowledge, attitudes, and behaviour (or practices) of youth and pregnant women, children's exposure to and

impact of second hand waterpipe tobacco smoke, the results of interviews with stakeholders and surveys of attitudes towards tobacco control policies linked to the Framework Convention on Tobacco Control (FCTC)<sup>1</sup>.

Phase 2 of the project is under development and is scheduled to start some time in 2006. In addition to research on the toxicology of the smoke and biomarkers, further work will be undertaken from the public health perspective (including additional knowledge, attitude and beliefs studies). The results of these studies will be published in future RITC monographs.

It is IDRC's hope that this volume will help to encourage further research in this relatively under-researched, but increasingly important, area<sup>2</sup>.

June 2006

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WHO Study Group on Tobacco Product Regulation (2005) Waterpipe tobacco smoking: Health effects, research needs and recommended actions for regulators. WHO, Geneva, 2005

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1 One of these articles has already been published in a refereed journal and another is soon to follow. These are: Tamim H., Akkary G., El-Zein A/, El-Roueiheb Z., El-Chemaly S. Exposure of Preschool Children to Passive Cigarette and Narghile Smoke in Beirut. European Journal of Public Health. In press.

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2 We are grateful to the various journals, authors and the WHO for their kind permission to reproduce their articles here.



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**TOBACCO SMOKING USING A WATERPIPE:  
PRODUCT, PREVALENCE, CHEMISTRY/TOXICOLOGY,  
PHARMACOLOGICAL EFFECTS, AND HEALTH HAZARDS**

A monograph prepared for the WHO Study Group  
on Tobacco Product Regulation (TobReg)

Alan Shihadeh  
Thomas Eissenberg

2005

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## I. Product Description

While we have been unable to locate a definitive history for the waterpipe, it appears that one variant or another has been used by the indigenous peoples of the Americas, Africa, and Asia to smoke tobacco and other substances (Chauouchi, 2000). While the geometries and materials of construction vary widely, the feature common to all waterpipes is a column of water through which the smoke bubbles prior to reaching the smoker. According to one history (Chattopadhyay, 2000), the waterpipe was invented in India by a physician to Emperor Akbar (ruled 1556 – 1605). In this account, tobacco was introduced near the end of Akbar's reign, but was opposed by a physician named Hakim Abul Fath for safety reasons. To address this concern, Abul Fath suggested that the "smoke should be first passed through a small receptacle of water so that it would be rendered harmless" (Chattopadhyay, 2000, p. 154). Thus, even early in its development, the waterpipe has been seen as a form of "harm reduction" for tobacco users. The focus of this manuscript is the *narghile* (aka shisha, hooka) waterpipe, common to Southwest Asia and North Africa (SANA), and currently undergoing a surge in popularity there and in the many parts of the world to which it is being exported.

Figure 1 illustrates the main features of the narghile. The head (fired clay, glazed or unglazed), body (metal or wood), water bowl (metal or glass), and corrugated hose (leather or nylon stretched over a wound flexible wire coil support) are the primary "elements" from which a narghile is assembled, and each is manufactured in several standard sizes. The tobacco is loaded in the clay head, where several large holes in the base allow the smoke to pass into the central conduit (typically made of brass) of the body that leads to the water bowl. Because the tobacco used has high moisture content, it does not burn in a self-sustaining manner; charcoal placed on top of the tobacco is used as the heat source. The characteristic flow passage diameter throughout the narghile is approximately 1 cm, while the overall height of a common narghile can vary from approximately 40 cm to more than a meter, and the length of the hose from 75 to 150 cm.

When a smoker inhales through the hose, a vacuum is created in the space above the waterline, causing smoke to bubble into the water bowl from the body. At the same time, air is drawn over and heated by the coals, with some of it participating in the coal combustion as evinced by the visible red glow that appears during each puff. The air and coal combustion products then pass through the tobacco, where due to convection and thermal conduction from the coals, the mainstream smoke aerosol is produced. By the time the smoke has traveled through the water bowl and hose, and reaches the smoker via the mouthpiece, it has been cooled to room temperature. Smokers feel

and hear the gentle gurgle as they smoke, adding to the sensory experience. During a smoking session, the charcoals are periodically replenished or adjusted to maintain a given smoke “density” as judged by the smoker. Usually a pile of lit charcoal is kept in a nearby firebox for this purpose. Smokers may opt to use quick-lighting charcoal briquettes to avoid preparing and maintaining a firebox every time they smoke.

There are two common tobacco configurations, referred to as *ma’assel* and *‘ajami*. With the *ma’assel* configuration, a relatively deep (approximately 3 cm) head is filled with 10-20 g of a flavored tobacco mixture (known as *ma’assel*, meaning “honeyed” in Arabic) and covered with an aluminum foil sheet that is perforated for air passage (Figure 1). Burning coals are placed on top of the aluminum foil. In the second case, that of the more traditional “unflavored” *‘ajami* tobacco (commonly referred to as *tombac*, or “tobacco” in Arabic), smokers mix a small amount of water with the dry, shredded tobacco to make a moldable matrix which they shape into a mound atop a shallow clay head (Figure 2). The coal is placed directly on the moisturized tobacco. In both configurations, products of the charcoal combustion are present in the mainstream smoke; that is, the narghile smoker actually “smokes” wood coal and tobacco together. In terms of the mass of material consumed in a smoking session, charcoal and tobacco are of comparable magnitude (Shihadeh, 2003).

Unlike the cigarette, narghile puffing possesses a relatively high volume/low resistance character akin to a free inhalation. Puff volumes of the order of 1000 ml are common, in contrast to puff volumes in the 30 – 50 ml range for cigarettes; thus a single narghile puff may displace as much smoke as a whole cigarette. A typical smoking session consists of hundreds of puff cycles executed over a period of approximately an hour with cumulative inhaled volume of the order

100 liters (Shihadeh et al, 2004). Particularly when smoked in the *ma’assel* configuration there is no well-defined end point; in general, the smoker simply stops when smoking is no longer appealing, whether due to a change in flavor as the tobacco is consumed, a sense of satiation, or a change in social circumstances (e.g., the end of a dinner during which a narghile was being smoked).

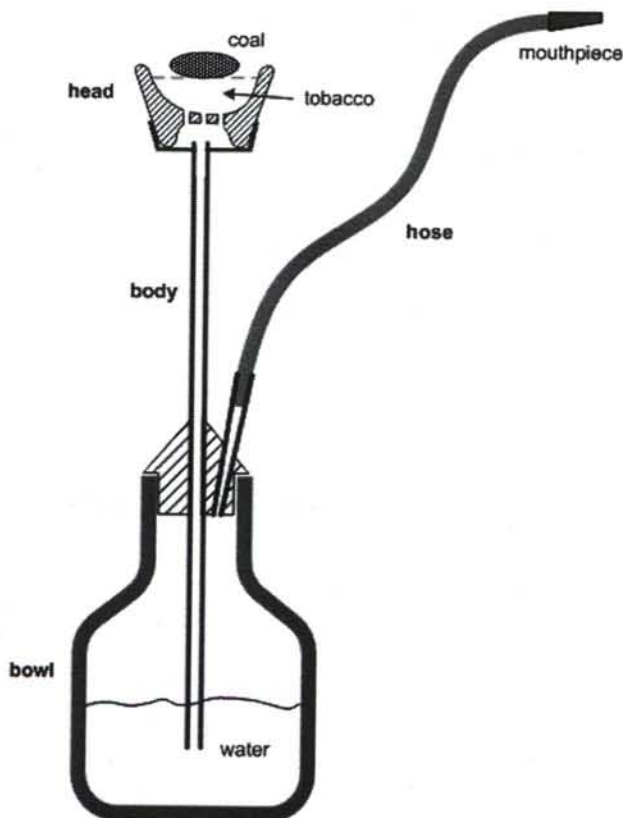
The smoking ritual is usually performed in the company of others (two or more persons may even share the same pipe). In Southwest Asia and North Africa, it is common to see children smoking waterpipes with their parents on family outings. Common settings include dedicated indoor narghile-coffee shops (usually the domain of older men), indoor or outdoor restaurants, homes, picnics, a sidewalk, or balcony. If smoked in a commercial establishment, the narghile is ordered (often from a menu of flavors) from a service worker who prepares one from an in-house stock of waterpipes. In this setting, a factory-sealed disposable plastic mouthpiece is provided with the narghile, ostensibly protecting the smoker from communicable diseases.

Outside of commercial establishments, people smoke their own waterpipes, usually purchased from dedicated supply shops, which typically also sell charcoal, tobacco, and a variety of accessories and – notably – a range of “reduced harm” products. These include activated carbon or cotton filter mouthpieces (*Vitafilter*, *NoNicotine* brands), chemical additives for the water bowl (brand names to be added), a plastic mesh fitted to the body outlet to create smaller bubbles in the water bowl (*Heba Filter*, see Figure 3), and a second miniature water-bubbler that is placed between the hose and the body. Standard waterpipes are inexpensive and can be afforded by almost anyone who means to purchase one. A regularly cleaned narghile can last for many years, with the exception of the leather hose which may be changed as it wears or residues build up in it.

In terms of its name recognition and availability probably the “Marlboro” of ma’assel waterpipe tobacco is the Nakhla brand, manufactured by Hadi El Ibiary and Co (Egypt). It is sold in 50 or 250 g packs in every tobacco supply and convenience market visited by us in the cities of the West Bank, Jordan, and Lebanon, and has authorized distributors located in 38 countries around the world ([www.nakhla.com](http://www.nakhla.com)). Indicative of its name value, we have found narghile tobacco sold in counterfeited Nakhla packaging. It is of note that the packaging of the Nakhla brands states that it contains “0% tar; 0.5% nicotine”. The most popular Nakhla ma’assel flavor is *toufaHtein*, or “two-apples”. Like other

ma’assel tobacco mixes, it is prepared by cooking shredded tobacco with fruit and molasses, and adding glycerin, other flavorings, and coloring agents. As the ma’assel is smoked, it releases a pleasant sweet aroma reminiscent of a cotton candy machine. Ma’assel is the favored tobacco type particularly among young smokers.

In contrast to the ma’assel mixtures, the “natural” tobacco blends used in the ‘ajami configuration are essentially dry and contain little or no added flavorings or colorings (reference to be added). They are similar in consistency to roll-your-own tobacco.



**FIGURE 1.** Waterpipe schematic. Head shown in ma’assel configuration. Dashed gray line represents the perforated aluminum sheet between the tobacco and coal.



**FIGURE 2.** Waterpipe head and tobacco in ‘ajami configuration. The tobacco rests on top of the head rather than inside it, and the coals are placed directly on the tobacco rather than on a perforated aluminum sheet.



## مصفاة Heba Filter

للاستعمال المزدوج



إحتياط رأس المصفاة  
للزجاجات الصغيرة  
Filter Spare head  
for small bottles



رأس المصفاة  
للزجاجات الكبيرة  
Filter head  
for big bottles



المصفاة الصغيرة  
Small Filter



المصفاة الكبيرة  
Big Filter

For Persian tobacco, widen the opening  
للتبناك وسع فتحة الرأس  
It is recommended to use a pipe with a wide opening  
ننصح بإستعمال ميسم واسع الفتحة  
الميسم (البن)  
Pipe



- \* Narghile Tube
- \* ماسورة النارجيلة
- \* To keep the sound going, notice the water level Adjusted according to bottle kind.
- \* للحفاظ على الصوت لاحظ مستوى الماء التقريبي يعدل حسب نوع الزجاجاة
- \* The filter level From 1 - 5 mm. Under water surface
- \* مستوى المصفاة من ١ إلى ٥ ملم تحت سطح الماء
- \* The Tube should be a little bit away from the filter bottom.
- \* يجب إبعاد الماسورة قليلا عن قعر الفلتر

## للاستعمال الصحيح نرجو قراءة النشرة

For proper use, please read this announcement

**Heba Filter** Reduces the harms resulting from tobacco, Persian tobacco, and molasses smoking by filtering and cooling the smoke inside the water in a better way. It is manufactured from chemicals-free medical and special materials capable of absorbing a portion of the nicotine, tar, and the like and casting the residue in the water. This has been proven scientifically and practically. The tests done in specialized research centres on one tobacco head revealed the following results: 46.6 mgs nicotine, and 100 mgs tar per one litre witch is double the usual amounts. This can be noticed from the contamination of both the water and the filter when you use the filter for the first time. In this way, the severity of cough and rattle will be less. It is also possible to limit the rumbling sound of the Narghile.

**مصفاة Heba** تقلل الأضرار الناتجة عن تدخين المعسل والتبغ والتبناك، وذلك بتصفية وتبريد الدخان داخل الماء بطريقة أفضل، وهي مصنعة من مواد طبية وخاصة وخالية من المواد الكيميائية قابلة لإمتصاص نسبة من النيكوتين والقطران وخلافه، وطرح الشوائب الباقية في الماء وقد ثبت ذلك علميا وعمليا من خلال التحليل التي أجريتها على الرأس الواحد من التبغ في مراكز البحوث المختصة: ما نسبته ٤٦,٦ ملغ من النيكوتين و١٠٠ ملغ من القطران في اللتر الواحد، مما يضاعف من النسب التقليدية ويلاحظ ذلك من تلوث المياه والمصفاة مما وهذا ما يجعلها تخفف من حدة الحشجة والسعال ويلاحظ ذلك عند إستعمالكم الأول لها. مع إمكانية الحد من صوت النارجيلة.

### كيفية الإستعمال:

- ✦ يتم إدخال المصفاة في الماسورة (السبع) وتبعد قليلا عن قعرها لتسهيل عملية التدخين (هذا للماسورة الطويلة) وتغمر في مياه النارجيلة بقدر من ٥ إلى ٥ ملم لتسهيل عملية الشفط.
- ✦ للحفاظ على صوت النارجيلة، يجب أن يكون مستوى سطح الماء عند أسفل عنق الزجاجاة وتقشير الماسورة الطويلة لتصل إلى ٥سم تقريبا قياسا من مستوى الماء المطلوب للتمكن من رفع المصفاة وتعديلها (أنظر الصورة).
- ✦ يربط رأس المصفاة عند تثبيتها في الماسورة ذات الصامولة (المزقة).
- ✦ يتم تغيير المصفاة بعد تلوثها أو استعمالها من ١٥ إلى ٢٠ مرة تقريبا.

### مصفاة ٣ بواحد

- ١- لتصفية أعلى ونتائج أفضل، يمكن استعمال فلتر مزدوج بعد إزالة المزقة اذا وجدت من أسفل الماسورة (أنظر الصورة).
- ٢- تستعمل المصفاة الصغيرة (منفردة) لأغلب الزجاجات الصغيرة والكبيرة بعد إزالة المزقة.
- ٣- يمكن إستعمال المصفاة الكبيرة (منفردة) للزجاجات الكبيرة مع الإبقاء على المزقة (ذات قطر أقصاه ١٨.١٥ ملم) أو إزالتها وذلك بتحسينها على النار وسحبها أو بقصها.

### How to use the filter

- \*For long tubes. The tube (el- Sabeh) is inserted in the filter a little bit away from its bottom to make smoking easier. Then the filter is immersed 1-5 mm in the Narghile water for easier dragging. (See the picture.)
- \*To keep the sound going, the level of the water surface should be at the bottle neck bottom. The long tube should be cut to be nearly 4 cms under the desired water level. (see the picture).
- \* The filter head should be wet with water when fixed into a tube with a nut.
- \*The filter is changed when it is contaminated or after using it nearly for 15-20 times.

### 3 in One (filter)

- 1-For more filtering and better results, use a double filter after removing the nut, if there is one, from the tube bottom.
- 2-A separate small filter can be used for most big and small bottles after removing the nut.
- 3- A separate big filter can be used for big bottles, either with the nut (15-18mm) diameter in place or after removing it by heating and pulling or by cutting it.

FIGURE 3. An example of a "reduced harm" narghile accessory sold in Lebanon. The device is attached to the outlet of the narghile body, just below the waterline of the bubbler. Note claims on product efficacy based on scientific testing in first paragraph of text. (Image is scanned from the instruction leaflet contained in the product packaging.)



## II. Prevalence \*

Although data on the spread of waterpipe use are scarce, available information paints a worrisome picture. Recent national and local surveys in Kuwait (Memon et al, 2000), Egypt (Mohamed et al, 2003; 2005), Syria (Maziak et al, in press), and Lebanon (Shediac-Rizkallah et al, 2002) have found that 20-70%, and 22-43% of the sampled populations has ever smoked or currently smokes the narghile, respectively.

A national survey in Kuwait shows that 57% of men and 69% of women had used waterpipe at least once (Memon et al, 2000). In Egypt, 22% of 6,762 men from two rural villages reported current or past use (Mohamed et al, 2003), while 4% of males and 0.7% of females sampled in a national survey (Mohamed et al, 2005) of 9088 adults reported *daily* use, with an aggregate mean of 6 narghiles smoked per day. Most users in Egypt reported starting waterpipe use after age 19 years (Gadella, 2003; Mohamed et al, 2003), though early initiation is also common: a recent study of 4994 adult males from 9 rural villages in Egypt found that approximately one third of narghile users initiated the habit between the ages of 10 and 19 (Neergaard et al, 2005).

Recent data also show that substantial numbers of adolescents and young adults are now smoking waterpipe. In Syria, for example, about half of university students report having ever used waterpipe, and about a quarter of males currently use it (Maziak et al, in press). The picture is similar in Lebanon, where, of 1,964 Beirut area university students, 30.6% of men and 23.4% of women reported current, weekly waterpipe use in 2001 (Tamim et al, 2003). Rates of waterpipe use are high among high school age students. Across several SANA countries, about 10-18% of 13-15 year olds use tobacco products other than cigarettes, most likely waterpipe (The Global Youth Tobacco Survey Collaborative Group 2002, 2003). Among Israelis, 22% of children 12-18 years of age reported using waterpipe at least every weekend (Varsano et al, 2003). In this sample, waterpipe use was three times more likely than cigarette smoking, and as common for boys as for girls. Additionally, a study of Arab American adolescents found that 26.6% of those sampled use waterpipe, emphasizing the global nature of this method, at least among Arabs (Hill et al, 2003).

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\* This section was taken from the waterpipe review by Maziak et al, and updated with recent work presented at the 2005 meeting of the SRNT.

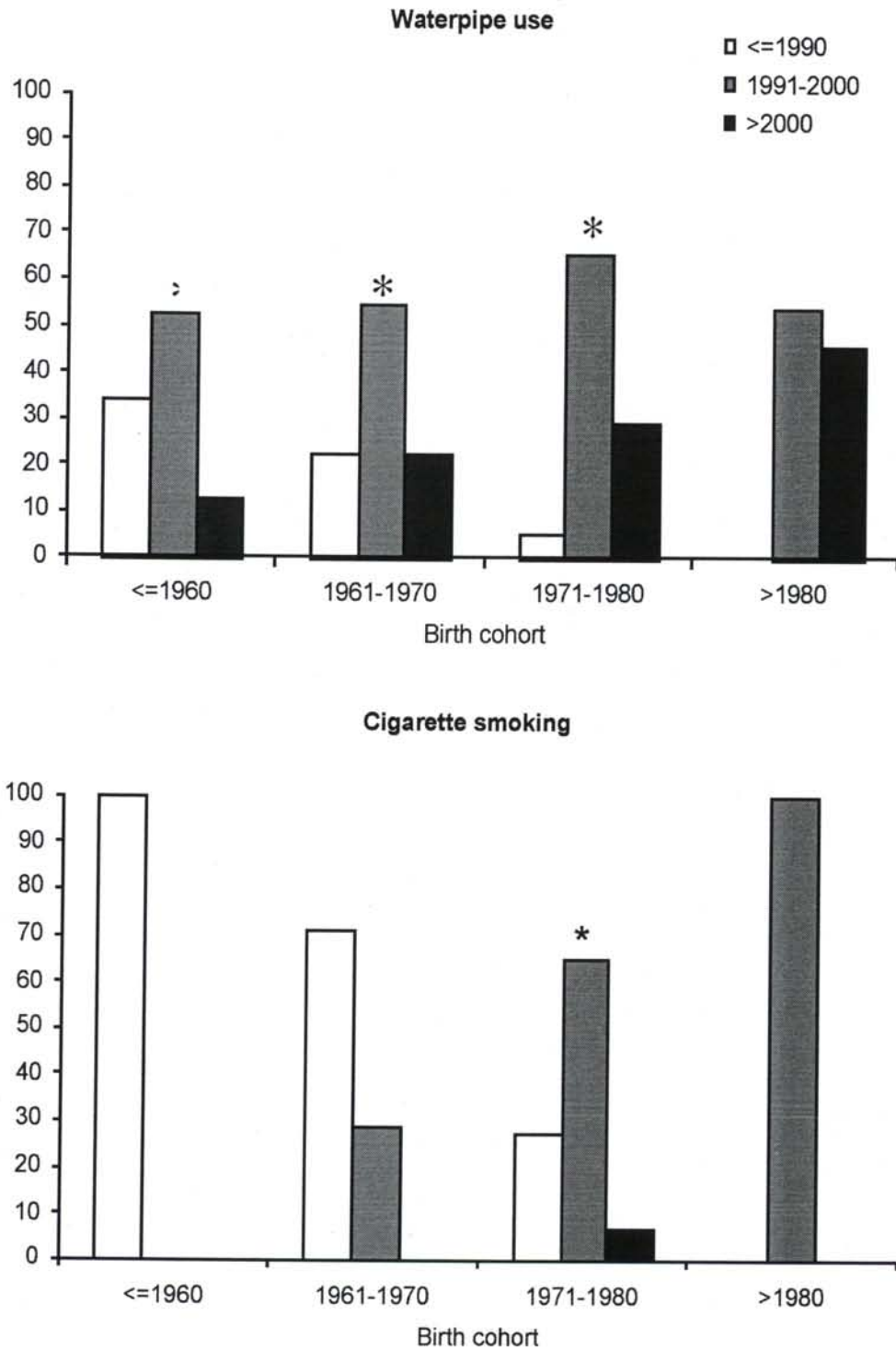
## Changes in prevalence over time.

Understanding changes in waterpipe use over time is challenging, because waterpipe use was rarely addressed in surveys conducted before 1990. To our knowledge, this issue has been examined empirically in only one population: Lebanese university students. A 2001 survey of students from several universities in Beirut reported 21.1% current waterpipe use (Tamim et al, 2003), while a survey conducted in 2002 at the American University of Beirut reported 28.3% current users (Chaya et al, in press). A similar increase was observed for individuals reporting that they had ever used waterpipe: 43% of entering students reported ever use in 2002 (Chaya et al, in press), compared to 30% four years previous (Shediaz-Rizkallah et al, 2001). Thus, among this population, the prevalence of waterpipe use may be increasing quickly.

Another approach to measuring changes over time is to compare the time period of initiation of waterpipe use and cigarette smoking across birth cohorts. As Figure 4 shows, there is a clear age-related pattern for cigarette smoking initiation in Aleppo, Syria, with older smokers initiating cigarette use in earlier decades. In contrast, across all age groups, most waterpipe initiation occurred during the nineties, implicating this decade as the waterpipe epidemic's beginning, at least in this Syrian city. Ma'assel was introduced in the 1990s, and this sweetened and flavored tobacco may play a significant role in waterpipe initiation. Ma'assel simplifies the process of waterpipe preparation: there is no need to moisten, shape, and dry the tobacco before use, as with other tobacco forms, such as 'ajami (which now accounts for less than 3% of waterpipe tobacco used by students;

Maziak et al, in press). Thus, like flavored and pre-packaged smokeless tobacco products in the U.S. that are recruiting new smokeless tobacco users (Kessler et al, 1997), flavored and convenient ma'assel in the SANA region appears to be recruiting new waterpipe users. Clearly this tobacco form is popular: revenues from ma'assel sales in Bahrain reached \$12 million in 1996 with a 36% increase in demand over previous years (Kandela, 1997). In a survey of 300 Egyptian waterpipe café patrons (Gadella et al, 2003), 74% used ma'assel.

While the available data are drawn from studies in the SANA region, newspaper reports of its burgeoning popularity (e.g. McNicoll, 2002; Barnes, 2003; Landphair, 2003; Edds, 2003; Gangloff, 2004) and "hookah bar" advertisements in college papers and on the internet suggest that waterpipe smoking is also becoming more prevalent in North America and Europe.



**FIGURE 4.** Period of initiation of waterpipe use (top) and cigarette smoking (bottom) for birth cohorts in Aleppo, Syria. Data from a 2003 cross sectional survey among a random sample of café customers in Aleppo (N = 268; 61.1% men; mean age 30.1+10.2; age range 18-68 years; response rate 95.3%). Asterisk (\*) indicates a significant difference between initiation time periods for each birth cohort (p<0.05). The figure is from Maziak et al., 2004.

### III. Smoke chemistry and toxicology

#### General Considerations.

By definition, tobacco smoke aerosols, like all aerosols, consist of particulate and gas phases. The gas phase contains volatile and semi-volatile compounds such as nitrogen, carbon monoxide (CO), nitric oxide, hydrogen cyanide, and a small proportion of the nicotine delivered to the smoker. The particle phase, consisting primarily of condensed liquid droplets is capable of scattering light, and gives tobacco smoke its visible character. It contains the preponderance of the nicotine. The condensed compounds can originate from simple evaporation from the tobacco (e.g. nicotine) or from *in-situ* chemical synthesis (e.g. benzopyrene) if temperatures are high enough. It is customary to classify the particulate phase as consisting of “tar” and nicotine. “Tar” is defined as the total particulate matter (TPM) collected by filtering the smoke through a standard glass fiber filter, minus the mass of nicotine and mass of water collected on the filter (i.e. Nicotine-Free Dry Particulate Matter”, or NFDPM). Thus “tar” actually is an aggregate measure of the mass of the thousands of compounds typically found in particulate phase of tobacco smoke, including polycyclic aromatic hydrocarbons (PAHs), phenols, nitrosamines, and metals. Because the particulate phase can deposit in the respiratory tract, it is the main vehicle by which smokers are exposed to carcinogens long after their last cigarette, up to several years later, depending on where the particles deposit. For cigarette smoke, yields for a number of known and suspected carcinogens are well correlated with the yield of “tar”; thus it is often interpreted as an index of cancer risk posed to the smoker. Because of the different ingredients and combustion conditions, narghile “tar” may be considerably different than cigarette “tar”, and caution is needed in interpreting one in terms of the other.

As mentioned in Section I, narghile smoke is the product of the tobacco and the charcoal. Thus in addition to those chemical compounds typically found in tobacco smoke, one can reasonably expect contributions from the charcoal to the gas and particulate phases of the smoke. Gas phase products of glowing charcoal have been found to include toxicants such as carbon monoxide and benzene (Olsson and Petersson, 2002), while particle phase products have been found to include a variety of carcinogenic PAHs (Dyremark et al, 1995). In addition, the aluminum foil used in the ma’assel configuration may be a source of metals in the smoke, though this has not been investigated.

While chemical composition of the smoke is important for understanding its potential health consequences, the particle size distribution and number density (number of particles per ml smoke) determine the dose and location of delivery in the respiratory system of the inhaled compounds. Inhaled individual particles of 0.1 to 1  $\mu\text{m}$  diameter are more able to penetrate the upper airways and deposit in the sensitive alveolar regions than particles larger or smaller than this range, though it has also been shown that high number density aerosols such as tobacco smoke can exhibit complex “colligative behavior” in which deposition dynamics are better predicted with consideration of cloud motion (exhibiting behavior akin to larger particles) in addition to individual particle dynamics (Broday and Robinson, 2003). Experimental inhalation studies of cigarette smokers indicate that 22-89% of the mainstream smoke particles inhaled with each puff remain in the smoker (Hinds et al, 1983; Robinson and Yu, 2001). It is generally accepted that the detailed physical properties of tobacco smoke particulate matter determine the deposition fraction and location, which in turn determine the occurrence, type and location of tumors found in the respiratory system.

### Testing methods.

Because it is not practical to measure detailed chemical composition during a real smoking session, studies on the chemical composition, toxicity, and carcinogenicity of cigarette smoke rely on standard smoking machine protocols to generate the smoke. Smoking machine studies are sometimes used in an attempt to predict and understand health effects of smoking, and to compare effects of varied tobacco blends, delivery methods, and puffing behavior. They complement in-vivo and epidemiological studies of smoking and have contributed significantly to a better understanding of cigarette smoke toxicity and carcinogenicity (Hoffmann et al, 2001) and to generating the evidence needed for anti-tobacco policies and action. For example,

for cigarette smoke, more than 4800 compounds, including 69 carcinogens, have been identified with smoking machine studies that span a period of more than 40 years (Hoffmann et al, 2001).

Machine puffing parameters (usually consisting of puff volume, duration, and interpuff interval) must be chosen to correspond to those of real smokers to produce a representative smoke aerosol in the lab. To do so, smoking topography measurements are performed on smokers in natural or clinical settings. Because of the many factors that differ between cigarette and waterpipe smoking (e.g. puff volume, duration of smoking episode, pressure perturbations caused by bubbling, etc), standard methods used in studying cigarettes cannot be adopted directly. Thus research is needed not only to study the detailed composition and physical properties of narghile smoke, but to develop the methods by which the smoke should be generated and sampled in the first place. The studies reviewed below made varying attempts to produce realistic narghile puffing regimens.

### Narghile smoke constituents.

Only six studies (Rakower and Fatal, 1962; Hoffmann et al., 1963; Sajid et al, 1993; Harfouch and Geahchan, 2003; Shihadeh, 2003; Shihadeh and Saleh, 2005) that addressed the chemical composition of narghile smoke could be located in the open literature.

Rakower and Fatal (1962) determined “tar” yields from a Yemeni narghile in the ‘ajami configuration, smoked using a puffing regimen consisting of 5 s duration puffs of 200 ml volume each, spaced at 60 s intervals. The regimen was chosen based on “examination of the habits of many narghile smokers” by unspecified methods. With 10 g of ‘ajami tobacco loaded, a yield of 84 mg of “tar” was found. The amount of charcoal placed on the head, and the total number of puffs taken were not reported. In addition to determining “tar” yield, Fatal and Rakower measured temperature

in the tobacco mound, which they found fluctuated between 600-650 °C. They interpreted this in relation to the peak temperatures found in cigarettes of circa 900 °C and speculated that the lower temperatures found in the narghile could result in a less carcinogenic “tar”. It is generally accepted in the combustion literature that higher temperatures result in greater formation of pyrosynthesized PAHs in pyrolysis zones, as would be expected to occur in certain regions of a cigarette or narghile head.

Hoffmann et al. (1963) used a conventional cigarette smoking machine to compare nicotine, benzo(a)pyrene, and phenols in the smoke condensates of various smoking devices, including the narghile water pipe in the ‘ajami configuration. While the experiments showed that narghile smoke contained significant quantities of these constituents – including benzo[a]pyrene in quantities per gram of burned tobacco exceeding those of “plain 85 mm cigarettes” – the value of the data is undermined by the fact that the standard smoking machine used in the study was not capable of generating the order of magnitude larger puff volumes (circa 500 ml) characteristic of narghile smoking; the tests were performed using the standard 35 ml, 2 second puff duration puff specified by the FTC for cigarette smoke testing. Furthermore, the investigators curiously did not use any coal to sustain the combustion, and as a result the tobacco had to be repeatedly ignited resulting in “difficulties in obtaining reproducible smoking conditions”.

Sajid et al (1993) measured carbon monoxide issuing from a South Asian hookah water pipe using a continuously running vacuum pump to generate the smoke. The smoke was trapped in a rubber balloon for off-line sampling. Rather than utilizing a puffing regimen to simulate a smoker, the pump was allowed to draw smoke continuously for 30 s through the water pipe at an average flow rate of 8 lpm for the duration

of the experiment. A variety of tobacco, charcoal types, and hookah sizes were tested. With 13 g of tobacco loaded in the head, the resulting carbon monoxide volume concentrations varied from 0.28 to 2.36%. They found that the tobacco type mixed with molasses, probably similar to the ma’assel narghile tobacco, consistently resulted in 30-40% less CO than the other two tobacco types tested, and that the smaller hookah exhibited CO concentrations 3 to 4 times greater than the larger hookah. The authors further found that CO concentration was unaffected by the presence of water in the water bowl for all smoking conditions. The most important variable was the charcoal type, with hardwood charcoal resulting in approximately 5 times more CO than when a softwood charcoal was used. While the authors did not comment on the issue, it is possible that the probably more effective (from a heat release rate perspective) hardwood charcoal resulted in a greater tobacco burn fraction during the 30 s smoking session, and that an actual smoker would use a smaller quantity of hardwood charcoal to achieve the same effect. It is also likely that the continuous 30 s puff resulted in unrealistically high temperatures in the coal and tobacco since realistic puffs are an order of magnitude shorter and followed by long (relative to puff duration) interpuff intervals which allow the temperature to decay before the next puff is taken. As a result, the CO fractions measured likely over-estimate the real fractions present in narghile smoke.

More recently, Shihadeh (2003) and Shihadeh et al (2005) investigated the chemical composition of ma’assel narghile smoke, for a variety of smoking regimens, coal application schedules, and with and without water in the bowl. A specially designed narghile smoking machine (Shihadeh and Azar, in review) was used to generate puffing regimens derived from detailed puff topography measurements in café settings (Shihadeh et al, 2004) using a narghile puff

topography device (Shihadeh et al, in press). In all cases, the “two apples” Nakhla ma’assel, quick lighting charcoal, and a single common narghile type was used. The results of these studies are summarized in Table 1. “Tar”, nicotine, CO, metals, PAHs and temperature measurements were made. In brief, key findings of these recent studies included the following:

- “Tar”, nicotine, and tobacco consumed in a single session depends strongly on the puffing regimen and coal application, with more intense smoking regimens resulting in greater quantities.
- The water bowl decreases the quantity of nicotine several-fold, but has negligible effect on the “tar” yields. This is consistent with the fact that nicotine is semi-volatile and is soluble in water, meaning that it can be readily stripped from the aerosol particles as they pass through the water.
- Relative to the yields of a single cigarette, many times the CO, “tar”, and PAH were produced by a single narghile smoking session.
- The average CO:nicotine ratio of narghile smoke is approximately 50:1 compared to approximately 16:1 for cigarettes, meaning that if smokers titrate for nicotine, narghile smokers using quick-light charcoal will be exposed to much greater quantities of CO.
- Similarly, chrysene:nicotine ratios are 15 to 20 times greater for narghile smoke than for cigarette smoke. Chrysene is a tumor initiator.
- While the yield of PAHs in a single narghile session exceeds by several times that of a single cigarette (Table 1), the *concentration* of PAHs in narghile “tar” is lower. That is, 1 mg of narghile “tar” does not ‘equal’ 1 mg of cigarette “tar”. This is fortunate for narghile

smokers, because a single smoking session produces as much FTC “tar” as 30 to 800 cigarettes.

- Peak temperatures measured just under the coal were circa 450 °C, which indicated that the smoke originating from the tobacco should be skewed towards products of simple distillation rather than pyrolysis or combustion (The same is not true for the charcoal, which may experience significantly higher peak temperatures in local reaction fronts.)
- The particulate phase is approximately 25% water by mass.
- By comparing the normal case to cases where charcoal alone is smoked and where tobacco is smoked using an electrical heater in place of the charcoal, it was deduced that the charcoal accounts for almost all of the CO yield under normal smoking conditions.
- Extremely high yields of heavy metals were observed (Table 1), though data was only obtained for two experiments and should be taken as preliminary.

Finally, Harfouch and Geahchan (2003) also quantified nicotine and benzo(a)pyrene from a narghile smoked with “two-apples” ma’assel tobacco, using a puffing regimen consisting of 300 2-second puffs of unknown volume (flow rate was not measured). They reported 1.90 mg/session nicotine and 52 ng/session of benzo(a)pyrene. This quantity of nicotine is similar to that found by Shihadeh (2003).

### **Particle number density and size distribution.**

Using a 7 stage cascade impactor (with a final stage cutoff diameter of 0.52 µm), particle number density and size distribution was estimated at the AUB Aerosol Research



Laboratory for the smoke exiting the narghile mouthpiece (Haddad, 2004). Using a puffing regimen consisting of 48 puffs of 3 s duration, 600 ml volume, and 15 s interpuff interval, a number density of approximately  $1 \times 10^8$  particles/ml, and a mass median diameter of  $0.8 \mu\text{m}$  was found. This compares to a number density of approximately  $2.5 \times 10^9$  particles/ml and a mass median diameter of approximately  $0.3 \mu\text{m}$  (Keith, 1982) for un-aged cigarette smoke. The larger mass median diameter and lower number density of the narghile are indicative of coagulation afforded by the longer time elapsed between the generation of the smoke in the head and its exiting the mouthpiece. While more detailed measurements and computational studies are needed to provide quantitative estimates of smoke particle dosimetry in the lung, this preliminary data shows that ma'assel smoke is a high number density sub-micron aerosol, indicating that – unfortunately for waterpipe smokers – respiratory deposition fractions will probably be similar to that of cigarette smoke.

## *IV. Pharmacology of tobacco smoking using a waterpipe*

The pharmacology of waterpipe use has not received systematic empirical attention. There may be a tendency to assume that waterpipe pharmacology is similar to cigarette pharmacology. However, any such assumption is challenged by differences in the tobacco smoked (e.g., waterpipe tobacco is highly sweetened and flavored, relative to cigarette tobacco; e.g., Hadidi and Mohammed, 2004), the maximum temperature reached by the tobacco (about 450 °C for a waterpipe, compared to 900 °C for a cigarette; Shihadeh, 2003), the duration of use episodes (about 45-60 minutes for a waterpipe, compared to about 5 minutes for a cigarette; Shihadeh et al., 2004; Shafagoj et al., 2002; Maziak et al., 2004), and puff topography (e.g., mean puff volume of 530 ml for waterpipe, compared to 42-70 ml for a cigarette; Shihadeh et al., 2004). Thus, understanding waterpipe pharmacology involves studying the pharmacokinetics and pharmacodynamics of nicotine, CO, and other active compounds delivered to waterpipe users who are smoking waterpipe tobacco in a manner that reflects real-world use.

To date, few studies have involved waterpipe users who are smoking waterpipe tobacco to examine nicotine exposure levels. In one such study (Shafagoj et al., 2002), 14 Jordanian men (mean age = 28 years; SD = 8) who used waterpipe to smoke tobacco at least 3 times/week, abstained from tobacco use for 84 hours (verified with plasma cotinine < 10 ng/ml) and then used a waterpipe to smoke 20 grams of ma'assel (Maziak et al., 2004) with a nicotine content of 3 mg/gram over a 45-minute period ("according to their own regular habit"; Shafagoj et al., p. 251; no information on charcoal application is provided). Blood was sampled via i.v. catheter and was analyzed for plasma nicotine level at baseline and 5 and 25 minutes during waterpipe use, as well as 0, 25, and 60 minutes after waterpipe use. Plasma nicotine levels at baseline were consistent with prolonged tobacco abstinence (mean = 1.11 ng/ml, SEM = 0.62 ng/ml). These levels increased during the 45-minute period of waterpipe use, and peaked, at the end of the use period, at a mean of 60.31 ng/ml (SEM = 7.58). By way of comparison, a recently completed study of 28 cigarette smokers in the U.S. showed that, after 96 hours cigarette abstinence, plasma nicotine levels were low (mean = 2.48 ng/ml, SEM = 0.50 ng/ml; Breland., 2005). However, after smoking a single own brand cigarette (smoking took 5 minutes, 33 seconds on average; venous blood was sampled, on average, 3 minutes, 8 seconds after the last puff of the cigarette), plasma nicotine levels increased to a mean of 7.80 ng/ml (SEM = 0.71). Thus, a single waterpipe use episode can deliver a substantial nicotine dose that may be equivalent to the dose delivered by approximately 10 cigarettes (and greater than that delivered by two 21 mg

transdermal nicotine patches, see Evans et al., 2005). One note of interest from this report is that two additional research subjects with the same waterpipe use history and who had complied with the 84-hour tobacco use abstinence criterion completed the study but their data were excluded from the analysis due to “dizziness, sweating, tachycardia with palpitation, gastrointestinal disturbances such as nausea, vomiting etc” (Shafagoj et al., 2002, p. 252). These signs, suggestive of acute nicotine intoxication, were accompanied with the observation that these individuals “were unaccustomed to smoke HB [hubble-bubble, a name for waterpipe] in the morning ...” (Shafagoj et al., 2002, p. 252). Another hypothesis for these acute effects in experienced waterpipe users might involve abstinence-induced dissipation of pharmacologic tolerance. As tolerance and dependence are sometimes well correlated, an empirical examination of nicotine tolerance in waterpipe users may be warranted.

Carbon monoxide (CO) is a combustion product inhaled by cigarette smokers, is used commonly as a marker of smoking status, and has been implicated in tobacco-related cardiovascular disease (Benowitz, 1997) as well as fetal tobacco syndrome (Niburg et al., 1985). Waterpipe use is also associated with CO exposure, and the carboxyhemoglobin level of waterpipe users is greater than that of non-smokers (e.g., Macaron et al., 1997; Zahran et al., 1985; Zahran et al., 1982). Relative to cigarette smokers, the carboxyhemoglobin level is waterpipe users is greater (Zahran et al., 1985; Zahran et al., 1982) or, at best, similar (Macaron et al., 1997). A laboratory study of the effects of waterpipe use (Shafagoj and Mohammed, 2002) reveals that 45 minutes of waterpipe use was associated with a linear increase in expired-air CO level over time (relative to baseline) with a peak increase of approximately 14.2 parts per million (ppm) at the end of the 45-minute use episode. CO levels remained significantly higher than baseline 60 minutes after smoking (approximately 12.9 ppm, on average) and 24 hours after

smoking (1.6 ppm, on average). By way of comparison, CO increased by a mean of 5.2 ppm in 34 cigarette smokers who had undergone 96 hours of tobacco abstinence and then smoked one cigarette of their own U.S. light or ultralight brand (Breland, 2005). Thus, a single waterpipe use episode involves prolonged exposure to CO during and after the episode, and these levels are higher than those associated with cigarette smoking.

Data regarding the pharmacodynamic effects of waterpipe use are presented in a subsequent report using identical methodology and 18 Jordanian men who used waterpipe to smoke tobacco at least 3 times/week (Shafagoj and Mohammed, 2002). As might be expected given the fact that waterpipe use involves nicotine delivery (Shafagoj et al., 2002) significant increases in heart rate, systolic and diastolic blood pressure, and mean arterial pressure were observed, and were well correlated with plasma nicotine level (i.e.,  $r_s > 0.51$ ,  $p_s < .001$ ). Relative to baseline, mean heart rate increased at 25 minutes into the 45 minute use period by 14.1 bpm (SEM = 1.9; an 18% increase in heart rate, on average) and peaked immediately after the conclusion of the 45 minute smoking period, with a mean increase of 16.0 bpm (SEM = 2.4; a 20% increase in heart rate, on average). By way of comparison, heart rate increased by a mean of 16.8 bpm (a 24% increase) in 34 cigarette smokers who had undergone 96 hours of tobacco abstinence and then smoked one cigarette of their own U.S. light or ultralight brand (Breland, 2005). Waterpipe-induced increases in systolic and diastolic blood pressure, as well as mean arterial pressure, were also observed at these time points, though the magnitude of the increases was approximately 6-8%, relative to baseline (Shafagoj and Mohammed, 2002).

The provocative results described here, regarding the nicotine and CO exposure and the cardiovascular effects associated with waterpipe use, highlight the need for further research regarding the pharmacokinetics and

pharmacodynamics of this method of tobacco smoking. Numerous unanswered questions remain, including how the pharmacokinetics and pharmacodynamics of waterpipe use are influenced by puff topography, duration of use episode, type of tobacco, type of charcoal, and a variety of other factors. Moreover, there have been no studies examining the development of tolerance and/or dependence in waterpipe users, the subjective effects of waterpipe use, and any changes in these effects over time/experience level. In short, the existing literature supports that notion that, like cigarettes, smoking tobacco using a waterpipe likely involves exposure to nicotine and CO, and, on a per use episode basis, this exposure is greater for waterpipe users than for cigarette smokers. In addition, waterpipe use clearly involves substantial cardiovascular effects. However, the dearth of literature on this topic, coupled with the public notion that waterpipe use is less dangerous than smoking (e.g., Kandela, 2000; Shafagoj and Mohammed, 2002; Zahran et al., 1982), and the fact that waterpipe use is spreading across the globe (Maziak et al., 2004) make clear the need more empirical attention to this potentially dangerous trend in tobacco use.

### **Abuse potential of tobacco smoking using a waterpipe.**

One definition of abuse liability is “the likelihood that a drug with psychoactive or central nervous system effects will sustain patterns of non-medical self-administration that result in disruptive or undesirable consequences” (FDA, 1990). Three facts suggest that waterpipe use involves (non-medical) self-administration of the psychoactive drug nicotine. That is, there are substantial amounts of nicotine in:

- Flavored and unflavored waterpipe tobacco (e.g., 1.8 – 41.3 mg/g; Hadidi and Mohammed, 2004).
- Smoke produced by a waterpipe (i.e., 2.25 mg produced by 100, 3 second

puffs with a 30 second interpuff interval; Shihadeh, 2003).

- Plasma of waterpipe users immediately after completing an *ad lib* waterpipe use period (Shafagoj et al., 2002).

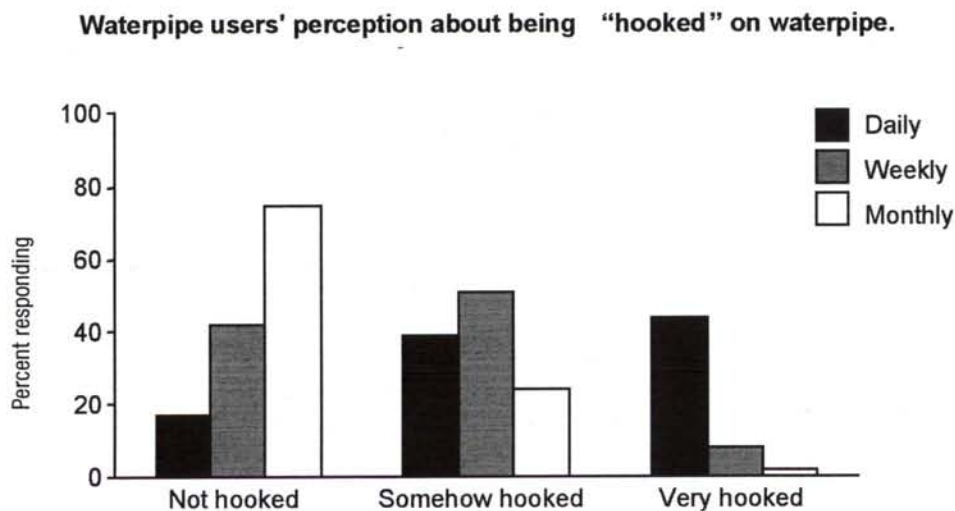
Thus, the abuse liability of tobacco smoking using a waterpipe may be substantial, inasmuch as waterpipe users are exposed to nicotine, a drug known to have considerable abuse liability (e.g. Schuh et al., 1997; Henningfield and Keenan, 1993; Henningfield et al., 1991).

The abuse liability of tobacco smoking using a waterpipe would be even more substantial if waterpipe use was associated with tobacco/nicotine dependence: a chronic condition involving repeated drug self-administration, despite known health risks, high financial costs, and multiple quit attempts. However, there has been little research investigating whether waterpipe users become tobacco/nicotine dependent, and the issue is made particularly problematic because the health risks of waterpipe use are generally not known to the waterpipe user (see, for example, Hadidi and Mohammed, 2004; Kandela et al., 2000; Shafagoj and Mohammed, 2002; Zahran et al., 1982; but see also Maziak, Eissenberg, Rastam et al., 2004; Asfar et al., 2005), and because some waterpipe users are also cigarette smokers (e.g., Asfar et al., 2005; Maziak, Hammal, et al., 2004; Neergaard et al., 2005). Nonetheless, one recent survey study addresses this important topic.

Maziak and colleagues (Maziak, Ward, and Eissenberg, 2004) surveyed 268 randomly chosen waterpipe users from randomly selected cafés that serve waterpipe in Aleppo, Syria (161 men, mean age = 30.1, SD = 10.2). Respondents were categorized based on frequency of use: daily (N = 64; 49 men), weekly (N = 129; 73 men), or monthly (N = 74; 38 men). All provided information regarding the setting in which they usually used waterpipe, their willingness to quit waterpipe use, the number of previous quit attempts, and their perception of how “hooked”

they were on waterpipe. Results revealed that more frequent users were more likely to use waterpipe alone, to use waterpipe at home, and to carry a waterpipe with them if they suspected that one would not otherwise be available. Also, more frequent users reported that the availability of waterpipe is important when they choose a restaurant or café. Importantly, while 96% of monthly users and 90% of weekly users reported that they believe that they could quit using waterpipe at any time, only 68% of daily users shared this confidence. Indeed, the majority (81.9%) of daily users reported being “somehow hooked” or “very hooked” on waterpipe, while only 26% of monthly users shared this perception (see Figure 1; Maziak, Ward, and Eissenberg, 2004). In addition, the majority (53.6%) of respondents reported that they perceived waterpipe use to be at least as harmful to health as cigarette smoking (Asfar et al., 2005). Thus, taken together, these survey results demonstrate that at least some frequent waterpipe users alter their behavior to maintain waterpipe use (i.e.,

carry a waterpipe; choose restaurants based upon waterpipe availability), perceive waterpipe use to be detrimental to their health, and recognize that they are “hooked” and may not be able to quit using waterpipe easily. Indeed, in a follow-up report, 28.4% of these waterpipe users reported an interest in quitting (89% of these individuals cited health concerns as a reason for their interest) and over half of those interested in quitting reported making an unsuccessful quit attempt in the past year (Ward et al., 2005). While far from definitive, these results are consistent with the notion that tobacco smoking using a waterpipe may support tobacco/nicotine dependence. Other indicators of dependence, such as abstinence-induced tobacco/nicotine withdrawal symptoms and signs, and waterpipe- and/or nicotine-induced withdrawal suppression in tobacco-abstinent waterpipe smokers await further empirical investigation.



**FIGURE 3.** The figure shows the responses to the item regarding “hooked” on waterpipe provided by daily, weekly, and monthly waterpipe users who were identified randomly from randomly selected waterpipe cafés in Aleppo Syria (figure adapted from Maziak, Eissenberg, and Ward, 2005).

## *V. Health hazards associated with tobacco smoking using a waterpipe*

Like cigarette smoking, smoking tobacco using a waterpipe is associated with a variety of health risks that include lung disease, cardiovascular disease, and cancer; environmental tobacco smoke and adverse pregnancy outcomes are also relevant to understanding the adverse health effects of waterpipe use. In addition, using a waterpipe to smoke tobacco may also be associated with some unique risks, including transmission of infection agents. These risks are discussed below, with the caveat that some studies addressing these issues have included waterpipe users who also smoked cigarettes, thus making difficult the task of comparing the relative risk cigarette smoking and waterpipe use.

### **Lung disease and waterpipe use.**

As described in a recent review (Maziak et al., 2004), several studies have examined the pulmonary effects of waterpipe use. In one, elevated levels of free radicals were found in peripheral blood neutrophils of waterpipe smokers (Sharma et al., 1997). These free radicals are known to mediate lung tissue injury (Macnee and Donaldson, 2003). In addition, several studies have assessed pulmonary function of waterpipe smokers compared to cigarette and non-smokers. For example, recent work from Egypt reveals that, relative to non-smokers, waterpipe users displayed greater levels of pulmonary impairment (assessed via spirometry; Hamada, Radwan, Israel et al., 2005; Hamada, Radwan, Zakaria et al., 2005; Kiter et al., 2000; see also Al Fayez et al., 1988, Salem and Sami, 1974) and these impairments are likely reflected in the greater incidence of chronic obstructive pulmonary disease observed in waterpipe users, relative to non-smokers (e.g., Zakaria et al., 2005; Mazen and Aurabi et al., 2000). Other research indicates that waterpipe use is associated with changes in lung biochemistry, as indexed by differences in bronchoalveolar lavage fluids (for a review, see Radwan et al., 2003). Finally, in a laboratory study of seven waterpipe using men, daily use was associated with increased levels of (plasma) 8-epi-PGF<sub>2a</sub>, a marker for in vivo oxidation injury that is also elevated in cigarette smokers (Wolfram et al., 2003). Overall, the observation that waterpipe use is associated with pulmonary dysfunction might be expected, given the smoke exposure associated with waterpipe use – a single one-hour waterpipe use episode, with mean puff volume of 530 ml and a 15 second interpuff interval (Shihadeh et al., 2004), might exceed the smoke exposure of several packs of cigarettes.

Indeed, some reports indicate that users of the waterpipe called “Goza” (a waterpipe with a smaller waterbowl bowl than shisha, narghile/arghile) may suffer more dyspnea and wheeze, relative to cigarette smokers (Salem et al., 1973). However, there are also reports suggesting that the pulmonary function of waterpipe users is not as impaired as cigarette smokers (e.g., Hamada, Radwan, Israel et al., 2005; Hamada, Radwan, Zakaria et al., 2005; Kiter, 2000) and, if valid, this observation may indicate that differences in smoke constituents and/or frequency of use may be relevant to the level of waterpipe-induced impairment of lung function.

### **Cardiovascular disease and waterpipe use.**

Few studies have examined the relationship between waterpipe use and cardiovascular disease. In one preliminary report of 292 waterpipe users and 233 non-smokers with coronary heart disease, 31% of cases were ever users of waterpipes, compared to 19% of controls (odds ratio = 1.9,  $P < .05$ ; Jabbour et al., 2003). Given that waterpipe use may be associated with predictive markers of atherosclerosis (e.g., serum sialic acid and lipid peroxides concentrations; see Ashmawi et al., 1993) the potential link between waterpipe use and cardiovascular disease deserves more investigation.

### **Cancer and waterpipe use.**

Waterpipe smoke contains carcinogens such as polycyclic aromatic hydrocarbons (Shihadeh and Saleh, 2005), and waterpipe extract produces degeneration and hyperkeratosis in rat mucosa (Abbas et al., 1987). Thus, *a priori*, there is reason to believe that waterpipe users might be at risk for at least some of the same smoking-related cancers as cigarette smokers. Indeed, as described in a recent review (Maziak et al., 2004) waterpipe use likely increases the

risk of bronchogenic carcinoma (Nafae et al., 1973), as well as lung (Lubin et al., 1990; Gupta et al., 2001), oral (El Hakim and Uthman, 1999), and bladder (Roohullah et al., 2001; Bedwani et al., 1997) cancers. Moreover, in a study comparing 35 healthy waterpipe users with 35 healthy, non-exposed controls, waterpipe use was associated with a significant increase in frequency of chromosomal aberrations and sister chromatid exchanges (Yadav and Thakur, 2000). Again, the link between cancer and waterpipe use is not definitive (except, perhaps, in a few case studies, see El-Hakim et al, 1999), and care must be taken to avoid conclusions based on waterpipe users who also smoke cigarettes. Much careful and well-controlled study is necessary to determine the cancer risks associated with waterpipe.

### **Environmental tobacco smoke and waterpipe use.**

A recent study of environmental tobacco smoke exposure in Aleppo, Syria reveals that, in this location, exposure to environmental tobacco smoke is virtually unavoidable (Maziak et al., 2005). Casual observation of a waterpipe café makes clear that some of this exposure may be related to waterpipe use: waterpipes produce substantial amounts of environmental tobacco smoke, particularly mainstream smoke exhaled by users. Moreover, exposure to waterpipe-related environmental tobacco smoke is not limited to cafés: In a survey of waterpipe use patterns in Aleppo, Syria, 19% of waterpipe users reported primarily home use, and nearly half (48.4%) of heavy waterpipe users (those who smoked at least once per day) did so mainly in the home. Unfortunately, little systematic research has focused exclusively on the effects of waterpipe on environmental tobacco smoke levels in cafés or homes. In one survey study of 625 Lebanese children aged 10-15 years, 70% of respondents reported that cigarettes or waterpipe were smoked at home (Tamim et al.,



2003). Importantly, for the 8.5% of children who reported being exposed at home to waterpipe smoke only, the odds ratio of having respiratory illness was 2.5 (95% confidence interval = 1.1-5.1) relative to a non-exposed group; this odds ratio was similar to that of children exposed to cigarette smoke only (i.e., 3.2, 95% confidence interval = 1.9-5.4; Tamim et al., 2003). Thus, there is some preliminary support for the notion that waterpipe-related environmental smoke exposure can produce adverse health consequences. As data addressing this issue accumulate and are translated into public awareness, informed waterpipe users may be urged to restrict waterpipe use in the home, and informed policy makers may consider restrictions that limit the damage done to vulnerable populations (e.g., banning waterpipe use in cafés and restaurants where/when children are served).

### **Risks associated with waterpipe use during pregnancy.**

CO exposure during pregnancy can harm the fetus, and is thought to underlie the low birthweight and low Apgar scores observed in neonates born to smoking mothers (i.e., fetal tobacco syndrome; Nieburg et al., 1985). Clearly, fetal tobacco syndrome is a risk for babies born to women who use waterpipes during their pregnancy: these women face increased risk of having babies with low birth weight, low Apgar scores and respiratory distress (Nuwayhid et al., 1998). In Beirut and its suburbs, 6% of the 576 pregnant women who were sampled reported that they smoked waterpipe during their pregnancies (Chaaya et al., 2003). In another survey of 864 pregnant women across Lebanon, similar rates of waterpipe use during pregnancy were observed (i.e., 4.3% for waterpipe alone, 1.4% for waterpipe and cigarettes; Chaaya et al., 2004). However, a distressing 70% of pregnant women in this survey reported living with a smoker (25% with a waterpipe smoker, 45% with a cigarette smoker; Chaaya et al., 2004).

Moreover, less than half of the women surveyed were aware that waterpipe smoke “contains addictive substances” and “contains carcinogens” though nearly three-quarters were aware that waterpipe smoking “affects the fetus” (Chaaya et al., 2004).

### **Other risks associated with waterpipe use.**

Aside from the direct effect of smoke constituents, the social dimension associated with waterpipe use may help spread infectious agents. That is, in many cultures, sharing a waterpipe is a common custom. For example, in Aleppo, Syria, the majority of waterpipe smokers among university students share the same waterpipe with their friends (Maziak, Fouad et al., 2004), in Beirut, Lebanon, 89.8% share the waterpipe (Chaaya et al., 2004), while, in Israel, 100% of children who use waterpipe reported that they pass the mouthpiece from mouth-to-mouth (Varsano et al., 2003). This practice can spread tuberculosis (e.g., Radwan et al., 2003) and viruses (herpes, hepatitis), particularly given that the temperature of smoke coming out of the waterpipe mouthpiece is likely similar to that of the ambient air (Shihadeh, 2003). The recent development and current use of disposable mouthpieces may help to reduce this risk.

As well as risking cancer, decreased pulmonary function, and cardiovascular disease, waterpipe users may also be vulnerable to other ailments (e.g., eczema of the hand, Oonder et al., 2002). Also, relative to nonsmokers, tobacco users are at increased risk for “dry socket” following tooth extraction (postextraction alveolitis) and this risk may be heightened further for waterpipe users (Al-Belasy, 2004). The fact that waterpipe smoke contains higher concentrations of some heavy metals, relative to cigarette smoke, suggests the potential for other waterpipe-specific health risks, though this issue has not been examined empirically.

## *VI. Conclusions*

In summary, the available evidence suggests that waterpipe use is on the rise across the globe, despite the fact that toxicology, pharmacology, and health effects all are consistent with the notion that this method of tobacco use shares many of the health risks associated with tobacco use. Smokers are exposed to large quantities of respirable particulate matter which has been found to contain significant amounts of PAHs and nicotine despite any of the purported benefits of the “water filter”. Likewise, the gas phase contains high levels of CO. Further work is needed in all areas, including method development (analytical chemistry, smoking machine protocols, and smoking topography measures) toxicant identification (quantify the components of the smoke which are thought to be the probable causative agents in tobacco related disease, with specific focus on waterpipe-specific toxicants associated with lower temperature and/or charcoal and aluminum use), pharmacology (identifying the toxicant exposure and dependence tobacco/nicotine level of waterpipe users), and health effects (via rigorous short-term clinical research and longer-term epidemiological study that control for concomitant cigarette use). Waterpipe users and policy makers should be advised of the probably risks of this tobacco use method, a global research effort should be initiated so that waterpipe use and effects can be understood more fully, and the worldwide tobacco control agenda should be modified to include waterpipe use in tobacco prevention and treatment interventions.

**TABLE 1.** Summary of studies on narghile smoke constituents using narghile-relevant puff parameters. The puffing regimen used in Shihadeh and Saleh 2005 was based on average parameters determined in a pilot study of café smokers in Beirut, conducted using a smoking topography instrument. Cigarette smoke data are shown for comparison.

	Shihadeh & Saleh 2005	Shihadeh 2003		Harfouch & Geahchan 2003	Rakower & Fatal 1962	single cigarette
<b>tobacco type</b>	ma'assel	ma'assel		ma'assel	'ajami	
<b>number of puffs</b>	171	100		300	nr	
<b>puff volume, ml</b>	530	300		nr	200	35
<b>puff duration, s</b>	2.6	3	3	2	5	
<b>Interpuff interval, s</b>	17	15	30	10	60	
<b>tobacco loaded/ burned, g</b>	10/4.7	10/3.3	10/3.0	7/nr	10/nr	
<b>coal loaded/burned, g</b>	8.7/nr	5.8/4.5	5.8/5.2			
<b>"tar", mg</b>	802	393	242		84	1 - 27* (11.2)**
<b>nicotine, mg</b>	2.96	2.11	2.25	1.90		0.1 - 2* (0.77)**
<b>CO, mg</b>	145					1 - 22* (12.6)**
<b>PAH</b>						
Benzo(a)pyrene, ng				52		20-40*
Phenanthrene, ng	748					200 - 400*
Fluoranthene, ng	221					9 - 99***
Chrysene, ng	112					4 - 41***
<b>METALS</b>						
Arsenic, ng			165			40-120†
Beryllium, ng			65			300†
Nickel, ng			990			0-600†
Cobalt, ng			70			0.13-0.2†
Chromium, ng			1340			4-70†
Lead, ng			6870			34-85†

nr – not reported

\* Reported ranges for commercial cigarettes, Jenkins et al., 2000

\*\* arithmetic mean for 1294 domestic cigarette brands tested by FTC for 1998 (FTC, 2000).

\*\*\* LGC, 2002.

† Hoffmann, D. and Hoffmann, I. Letters to the Editor, Tobacco Smoke Components. Beitr. Tabakforsch. Int., 18, 49-52

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**INVESTIGATION OF MAINSTREAM SMOKE  
AEROSOL OF THE ARGILEH WATER PIPE**

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## *Abstract*

A first-generation smoking machine and protocol have been developed in order to study the mainstream smoke aerosol and elucidate thermal-fluid processes of the argileh water pipe. Results using a common *mo'assel* tobacco mixture show that, contrary to popular perceptions, the mainstream smoke contains significant amounts of nicotine, "tar" and heavy metals. With a standard smoking protocol of 100 puffs of 3 s duration spaced at 30-s intervals, the following results were obtained in a single smoking session: 2.25 mg nicotine, 242 mg nicotine-free dry particulate matter (NFDPM), and relative to the smoke of a single cigarette, high levels of arsenic, chromium and lead. It was found that increasing puff frequency increased the NFDPM but had little effect on nicotine delivery, while removing the water from the bowl increased by several-fold the nicotine, but had little effect on NFDPM. It was also found that the charcoal disk heat source contributed less than 2% of total particulate matter (TPM), and that characteristic temperatures of the tobacco varied from 450 °C nearest the heat source to 50 °C furthest away, indicating that the NFDPM is likely a result of devolatilization rather than chemical reaction, and will thus differ significantly in composition from that of cigarette smoke.

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*Keywords:* Argileh; Shisha; Hooka; Hubble-bubble; Water-pipe; Nicotine; Tar; Tobacco

*Abbreviations:* DPM, dry particulate matter; FTC, Federal Trade Commission; gTPM/gTob, grams of TPM per gram of tobacco consumed; TPM, total particulate matter; NFDPM, nicotine-free dry particulate matter; "tar", TPM – (nicotine+water).

# 1. Introduction

A sharp increase in the use of the argileh water pipe has been noted in recent years in south-west Asia and north Africa, particularly among young people (Attah, 1997; Shediak-Rizkallah et al., 2002). The rise in popularity appears to be correlated with the advent on store shelves of an array of fruit-flavored tobacco mixtures, which list “molasses” as a primary ingredient. As the tobacco mixture is smoked, it releases an aroma of caramelizing sugar, similar to that from a cotton candy machine. In this form, the flavored tobacco mixture is popularly known as *mo’assel*, and is contrasted to the more traditional ‘unflavored’ tobacco, known as ‘*ajami*’ which is favored by older generations, especially men.

A widespread perception among smokers, and even physicians (Kandela, 1997), is that the water through which the smoke bubbles acts as a filter, rendering it considerably less harmful than that of cigarettes; this perception may be aided by the fact that the smoke is significantly cooled as it passes through the water bowl and long delivery pipe, adding to its ‘smoother’ quality. There have been few studies of the health effects on argileh smokers (Macaron et al., 1997; Zahran et al., 1982, 1985; Al-Fayez et al., 1988; Nuwayhid et al., 1998; El-Hakim and Uthman, 1999), and none to determine the chemical profile of the smoke they inhale, or the importance of the physico-chemical processes unique to the argileh. This has left researchers, public health officials and the general public with little information to rank the potential hazards of argileh smoking.

The research described here is a ‘first-cut’ at developing the methods to characterize the mainstream smoke and important thermal-fluid phenomena of the argileh. Preliminary results using these methods are reported.

## 1.1. Smoke formation and transport in the argileh

Plate 1 illustrates the main features of the argileh water pipe. The head, body, bowl and hose are the primary ‘elements’ from which an argileh is assembled, and each can be purchased separately in standard sizes. The smoker typically presses the fired-clay head onto the metal body, using tissue paper or a rubber fitting at the joint to make a seal. The interface between the body and the glass water bowl, which is typically rinsed and re-filled each smoking session, is similarly sealed, as is the interface between the body side-arm and hose. The flexible hose is typically made of leather or other fibrous material, with each end terminating in a hollow wood fitting.



When a smoker inhales through the hose, a vacuum is created in the headspace of the water bowl sufficient to overcome the small (typically 3 cm H<sub>2</sub>O) static head of the water above the inlet pipe, causing the tobacco smoke to bubble into the bowl. Depending on the flow rate, the static head of the water is generally the primary flow resistance in the system felt by the smoker. During each puff, air is drawn over and heated by the coals, some of it participating in the coal combustion, as evinced by the visible red glow that appears during each puff. It then passes through the tobacco, where, due to hot air convection and thermal conduction from the coal, the mainstream smoke aerosol is produced. Unlike the cigarette, there is practically no visible sidestream smoke rising from the head either during or between puffs.

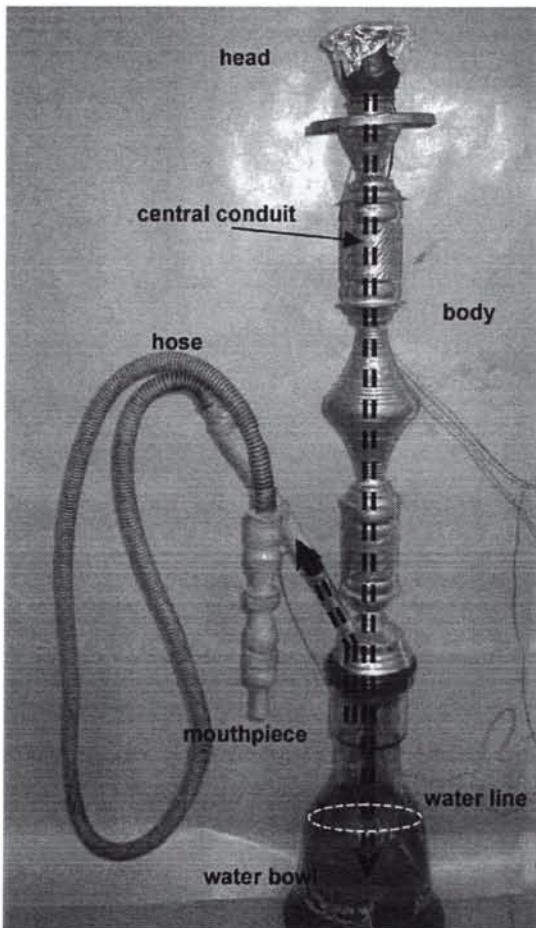


PLATE 1. A typical argileh water pipe.

While the argileh body and bowl are manufactured in a variety of sizes, there are two common configurations for the clay head in which the tobacco is placed, depending on whether the smoker is using *mo'assel* or *'ajami* tobacco. When *mo'assel* is used, smokers fill a relatively deep (approximately 3 cm) head with the tobacco mixture (10-20 g), and cover it with an aluminium foil sheet that they perforate (approx. 1mm diameter holes) for air passage. The already burning coal is placed on top of the aluminium foil, and may be changed a number of times during a particular smoking session. In the second case, that of the traditional *'ajami* tobacco, smokers mix a small amount of water with the pre-shredded and dried tobacco to make a moldable matrix which they then shape into a small mound atop a shallow head. The burning coal is placed directly on the moisturized tobacco, and both are directly exposed to the surrounding air.

In both cases flow passages are located at the base of the clay head to allow the smoke to pass into the central conduit of the body that leads to the water bowl. Owing to its high moisture content, the limited availability of air (particularly with *mo'assel* smoking), and the large heat-conducting surface of the head with which it is in intimate contact, the tobacco does not burn in a self-sustaining manner; it requires the continuous external heat source provided by the wood-derived charcoal. Products of the charcoal combustion are therefore also present in the smoke.

Because of the long path traversed by the smoke as it passes from the head, through the body, to the water bowl, and through the hose to the smoker, there are ample opportunities for gas and particulate phase deposition, diffusion, and evaporation/condensation processes to occur.

## 2. Materials and methods

### 2.1. Smoking machine development

The argileh 'puff' can be characterized as a low-resistance inhalation in which a large fraction of the smoker's chest cavity is filled with smoke, corresponding to a volume of the order of 1 l (average tidal air during quiet respiration is about 500 ml for an adult male; maximum air displaced is 3700 ml). This is an order of magnitude greater than the 35-ml puff volume specified by the FTC test method for cigarettes.

Assuming that the flow can be characterized as quasisteady during the puff, a simple smoking machine was designed using a high flow capacity vacuum pump and direct action three-way solenoid valve and timer, as illustrated in Fig. 1. The vacuum pump was operated continuously at a flow rate of 6 l/min during each smoking run, with the suction sent either to the argileh or to atmosphere by the solenoid valve, with flow control obtained by a precise needle valve and calibrated rotameter.

As shown, the smoke aerosol was split into four streams immediately downstream of the hose outlet and each stream drawn through a single 47-mm Gelman type A/E glass fiber filter pad before being recombined. Each pad was held in a transparent polycarbonate holder, also manufactured by Gelman. The flows were split to reduce filter loading to approximately 100 mg of smoke condensate per filter for each smoking session. (ISO 4387:1991 specifies that up to 150 mg of tobacco smoke condensates may be collected on a 47-mm glass fiber filter pad.) A secondary filter was placed downstream of the 4-to-1

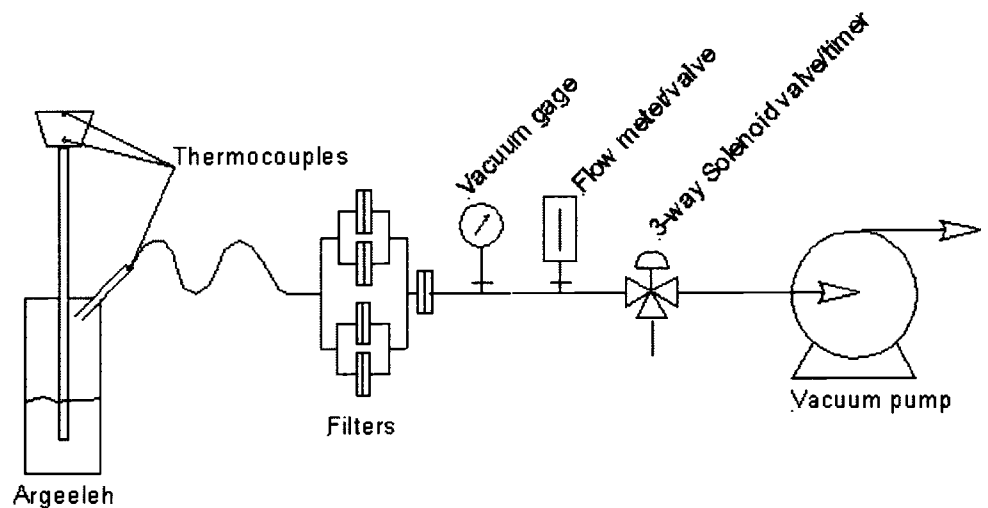


FIG. 1. Schematic of the smoking machine apparatus

junction and weighed before and after each run to ensure that there was no breakthrough. All flow lines were made of 1/4-inch ID transparent Tygon tubing. A vacuum gauge was installed downstream of the filters.

## 2.2. Temperature measurements

Rapid response Type-J thermocouples of 0.01-in. diameter were installed at several locations: (1) just below the aluminium foil, on top of the packed tobacco; (2) within the tobacco, at a depth of 2.5 cm below the tobacco surface; (3) at the flow outlet of the clay head; and (4) at the inlet to the flexible hose. The data were acquired by a PC at a rate of four sample sets per second via a Pico Technology TIC-08 data acquisition board. To verify that the thermocouples were of sufficiently rapid response to follow the relevant temperature dynamics, a 0.005-in. diameter thermocouple was used in parallel to thermocouple (1) and the signals compared for a limited number of experiments.

## 2.3. Smoking protocol and operating procedures

In the absence of detailed smoking topography data for argileh users, and to provide reasonable values for the number of puffs, their duration, frequency and volume, a pilot study was conducted in which 28 *mo'assel* smokers were observed anonymously in local coffee shops. Because the glass bowl of the argileh is transparent, the beginning and end of each puff could be observed visually from a distance, and event timing recorded manually with a stopwatch. In addition to recording the puff/rest interval timing, number of puffs, and total smoking session time, the amount of tobacco mixture used to pack the head, and the amount burned during the smoking session was determined with a portable digital scale by measuring the prepared head weight before and after each session, as well as the weight of the

smoked head with the tobacco removed. This was done in co-operation with the service staff of the coffee shops who allowed a research assistant to weigh the argileh heads leaving and returning to the service area.

The puff and rest intervals were calculated for each smoking session by summing the respective times over the entire session and dividing by the number of puffs.

Each of the 28 smoking sessions was therefore represented by average puff and rest intervals, and number of puffs, and these numbers, in turn, were averaged over the 28 sessions. The results are given in Table 1.

**TABLE 1** Results of pilot study of argileh smokers (N=28)

	Average	Range	SD
Puff duration (s)	2.77	1.6-4.6	0.6
Rest interval (s)	30.0	10.2-53.9	11.7
Session duration (min)	50.6	19.0-83.9	16.1
Total number of puffs	101.1	50-203	38.1
Tobacco loaded (g)	9.4	6.9-11.7	1.2
Tobacco consumed (g)	3.9	1.8-5.0	0.9

Based on these preliminary measurements, a standard smoking session was defined as 100 puffs, duration 3 s, with 30 s between puffs (i.e. a cycle period of 33 s). The experimental puff volume was set to 300 ml, in order to give a similar amount of tobacco burned in 100 puffs to what was found in the field study, using the standard smoking regimen. For comparison, an "accelerated regimen" was also defined in which the interval between puffs was reduced to 15 s, all else being the same.

To standardize the experiments, self-starting charcoal disks manufactured by Three Kings Charcoal Co. (Holland) sold widely in tobacco supply shops were utilized, at a rate of one disk for each 100-puff smoking session. The disks were held by a metal tong with the radial axis of the disk in a vertical plane, and the bottom side

exposed for 5 s to the flame of a butane cigarette lighter, and held for an additional 100 s in the same position to ensure that the ignition agent had been entirely consumed before placing the charcoal disk on the argileh head (the reaction front visibly traverses the entire length of the disk in roughly 45 s after lighting). The first puff was initiated 15 s after the disk was placed on the head. One disk, weighing 5.8 g, was used in each smoking session, and its weight recorded before and after each session.

Three 250-g packages of the locally most popular type of *mo'assel* tobacco mixture (“Two Apples” flavor, manufactured by Adel El-Ibiary & Co., Egypt) were mixed together, and large agglomerations and stems removed (accounting for approx. 10% of the as-purchased weight) so as to create a more homogeneous mixture for the experiments. The mixture was parceled into airtight packets of roughly 12 g each, and stored in a sealed container at 20 °C in the dark for the duration of the study. For each smoking run, an individual packet was unwrapped and 10 g of tobacco mixture was loaded into the head, essentially filling it.

A small aluminium foil sheet (approx. 9 cm X 9 cm) was used to cover the head, and was perforated according to the 18-hole pattern shown in Fig. 2. Rather than wrapping the foil tautly over the head, enough slack was left to allow an approximately 2 mm depression relative to the head rim to be formed in order to help hold the coal disk in place during the

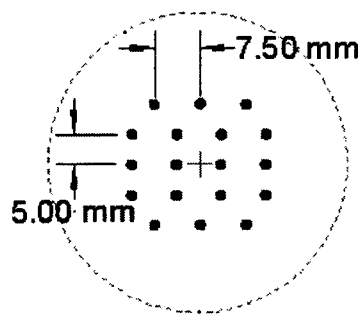


FIG. 2. Aluminium foil perforation pattern used in current study.

smoking session. It was found that when the foil was wrapped tautly, it tended to form a “drumhead” that vibrated at the bubbling frequency, particularly in the second half of the smoking session, when the tobacco under the foil had become stiff and its vibration-damping properties reduced. This caused the coal to migrate, thereby necessitating periodic intervention during the session to prevent it from marching entirely off the head (it is quite usual for an argileh smoker to adjust the coal during a smoking session). With the depression, the need for intervention was greatly reduced or eliminated altogether, though the bubble-induced vibration remained noticeable.

After each smoking run, the water in the bowl was discarded, the bowl partially re-filled, shaken by hand for several seconds, and discarded again. The bowl was then re-filled with tap water to the water level indicator line (corresponding to a volume of 785 ml). The head was emptied, wiped dry with a paper towel, and repacked with the prescribed 10 g of tobacco mixture. In keeping with common practice at local restaurants and coffee shops, there was no attempt to clean any of the flow passages within the argileh between runs, though some deposits in the body pipe were visible, with a thickness of the order 0.1 mm.

To further reduce variations between smoking sessions, all flow interfaces—head/body, body/bowl, and sidarm/hose—were externally sealed each smoking session with one layer of electrical tape. In addition, the body and water bowl were joined via a rubber sleeve that was originally supplied with the argileh. The ceramic head fit tightly into the body as supplied with no rubber sleeve.

The apparatus used in this study was obtained from a stock of in-use argilehs at a local popular restaurant frequented by argileh smokers. Some 40 standard smoking sessions were conducted in the lab prior to the first set of nicotine and water determinations. It is expected that aerosol

deposition on the various argileh flow surfaces is greater when the apparatus is new than when it is well-seasoned, though this remains to be verified experimentally. The dimensions of the argileh used in the study are listed in Table 2.

**TABLE 2** Argileh dimensions used in current work

Part	Dimension	Measurement
Clay head	Inner depth	3 cm
	Overall inner diameter	4.5 cm
	Number of gas outlet passages	4 cm
Body conduit tube	Length	56.5 cm
	Inner diameter	0.8 cm
	Immersion depth below water surface	4 cm
Hose	Length	155 cm
	Outer diameter	1.5 cm
Water bowl	Overall height	24.5 cm
	Water volume to fill line	785 cm

## 2.4. Chemical analysis

For each smoking run, the weight of the loaded, foilwrapped head was recorded before and after each smoking run, as were the filter holders. The smoke condensates from two filter pads were extracted in ethyl acetate and toluene and analyzed by GC-MS to quantify the nicotine concentration according to standard methods (Siegmund et al., 1999). A third filter pad was analyzed for water content using Karl-Fisher titration in which the entire filter pad was introduced directly from the filter holder to the reaction vessel. In addition, for a small subset of cases a metals analysis was conducted by ICP-MS of microwave-digested filter pad in accordance with EPA Method 3051.

TPM was determined gravimetrically as the total weight increase of the filter holder assembly. The nicotine content was determined for filters 1 and 2, and the water for filter 3, and the total nicotine

and water condensates collected in a given smoking session were estimated by assuming that the respective analyte scaled linearly with TPM for that session:

$$\text{Total Nicotine} = \text{TPM}_t \cdot [(\text{Nic}_1 + \text{Nic}_2)] / (\text{TPM}_1 + \text{TPM}_2)$$

and

$$\text{Total Water} = \text{TPM}_t \cdot (\text{Water}_3 / \text{TPM}_3)$$

where

$\text{TPM}_i$             TPM collected on filter  $i$   
 $\text{TPM}_t$              $\text{TPM}_1 + \text{TPM}_2 + \text{TPM}_3 + \text{TPM}_4$

$\text{Nic}_i$             nicotine on filter  $i$  as determined by GC analysis

$\text{Water}_3$         water contained in the condensates of filter 3, determined by KF titration

Nicotine-free dry particulate matter (NFDPM) for a given experiment was calculated as

$$\text{NFDPM} = \text{TPM}_t - \text{Total Water} - \text{Total Nicotine}$$

Because the TPM and water content were found to be three orders of magnitude greater than the nicotine, the NFDPM is essentially equal to the DPM.



## 3. Results

### 3.1. Temperature

Fig. 3 shows typical temperature profiles during a 100-puff 3/30 standard smoking session, where temperatures ranging from 450 °C closest to the coal to 50 °C at the head outlet were recorded. Each temperature spike corresponds to a puff as air is drawn over the burning coal and into tobacco mixture. Owing to this convective heating, as well as the continuous heat conduction between puffs from the coal to the tobacco (as evidenced by steady-state tobacco temperature of 75 °C in a quiescent burning session with no puffs taken), the mean tobacco temperature continues to rise, peaking near the end of the smoking session, by which time the majority of the coal's chemical energy has been released. It should be noted that the head outlet temperature during puffing is represented by the peaks in the temperature signal; the off-puff temperatures between peaks simply signals the thermal environment of the head outlet while no gases are flowing through it. The puff temperature reaches approximately steady state after 700 s, while the off-puff temperature approximately stabilizes after an additional 500 s, indicating the approach of thermal equilibrium of the clay head.

The foil temperature record also illustrates the puffing cycle, with local temperature maxima resulting from the temporary increase in availability of oxygen to the burning coal, an expected phenomenon in the mixing-limited regimen characteristic of charcoal briquette combustion. Also apparent from Fig. 3 is that by the time the smoke aerosol reaches the hose inlet, it is already at a temperature essentially equal to that of the ambient air; no significant heat transfer occurs in the hose.

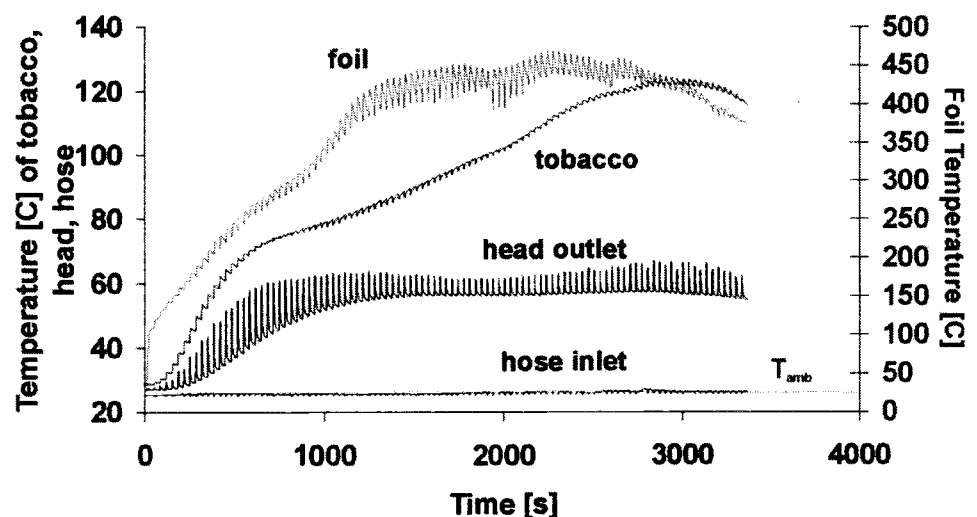


FIG. 3. Temperature profile for a standard smoking session.

### 3.2. Tobacco mixture consumed

Fig. 4 shows the effect of puff volume on amount of tobacco mixture consumed in a single smoking session. The positive correlation with puff volume can be attributed to increasing convective mass transfer from the tobacco mixture resulting from (a) the greater bulk transport of scavenging air through the head, and (b) the higher average gas temperature (observed experimentally) which results from the higher combustion rate associated with the increased oxygen availability to the coal.

For the 15 smoking sessions run at a puff volume of 0.3 l, the average tobacco mixture consumed was 3.1 g, with a standard deviation of 0.2 g. This compares to the field study mean of 3.9 g and standard deviation of 0.9 g, a difference most likely indicating that the heat release of the single charcoal disk used in the machine smoking was somewhat less than the coals used in actual smoking conditions. The scatter in the data shown in Fig. 4 is likely indicative of irregularities in hand-packing the tobacco mixture into the argileh head, as well as

differences in the burning history of the charcoal disk possibly caused by the varying degrees of coal fracture, disintegration, and migration on the head which resulted from its “drumming” at the bubbling frequency. Further, in cases where a significant fraction of the coal disk had disintegrated, some of the ashes were inducted into the tobacco mixture through the breathing holes in the aluminium foil cover of the head, and thus included in the final head weight. A comparison of the final weight of the charcoal disks that remained intact to those that were badly disintegrated by the end of the smoking session indicates that up to 0.1 g of coal ash could be inducted into the head. The weight of the coal, its surface area, and its location on the head are also likely to impact the combustion and heat transfer dynamics.

To account for the variability in amount of tobacco consumed under a particular smoking regimen, and to distinguish this effect from others of interest, the data shown in Figs. 5 and 6 are plotted versus amount of tobacco consumed.

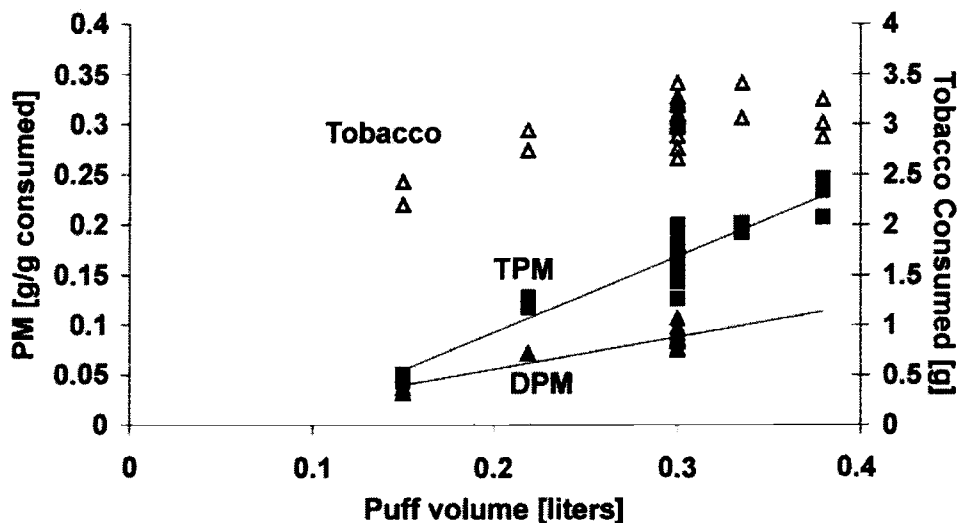


FIG. 4. Effect of puff volume on tobacco consumed and TPM for 100 3-s puffs with 30-s rest intervals. Condition with water in bowl. Lines represent.

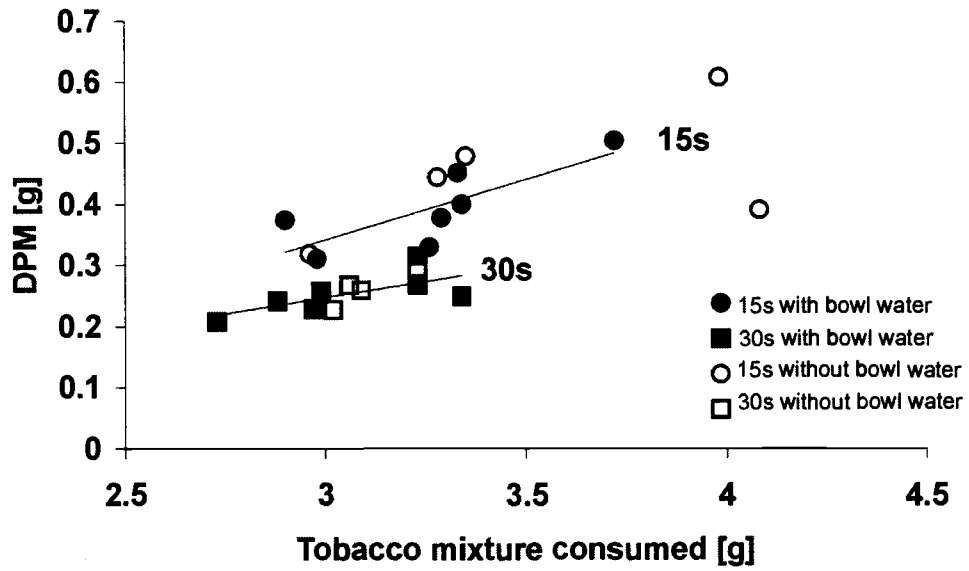


FIG. 5. Effect of bowl water and puff frequency on NFDPM. Empty symbols indicate runs without bowl water; filled symbols indicate runs with bowl water.

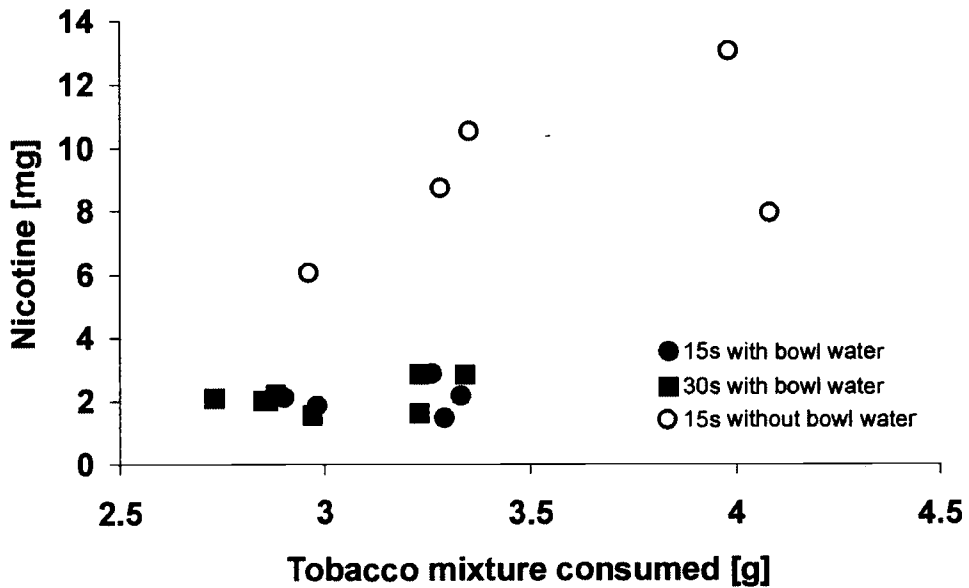


FIG. 6. Effect of bowl water and puff frequency on nicotine.

### 3.3. TPM, NFDPM, nicotine and water

Also shown in Fig. 4 is the increasing production of particulate matter with increasing puff volume. The normalized TPM concentration, calculated as the TPM per gram of tobacco consumed per unit volume of gas drawn through the filter, is approximately constant at 5.6 g TPM/g Tob/m<sup>3</sup>, except at the smallest puff volume of 0.15 l, which yields a normalized TPM concentration of 3.2 g TPM/g Tob/m<sup>3</sup>. This indicates that in the 0.2-0.3 l-puff volume range, the TPM is determined by how much air is made available to carry it away from the devolatilizing tobacco mixture. At the standard smoking puff volume of 0.3 l, the 5.6 g TPM/g Tob/m<sup>3</sup> corresponds to an average TPM concentration of 17.4 g TPM/m<sup>3</sup>, which is of the same order of magnitude as the concentration of 9.25 g TPM/m<sup>3</sup> found for the 1R5F reference cigarette, representative of the “ultra-low tar” category, smoked under the FTC protocol (Bogerdig et al., 1997).

In experiments carried out with no tobacco in the head it was found that the TPM collected was up to 7 mg, indicating that the coal disk provides a small contribution to the 400 mg of TPM collected under standard smoking conditions. This is not to discount its potential contribution to the risk posed by argileh smoke, since its chemical composition is unknown and may contain carcinogenic compounds not present in the particulate matter originating from the tobacco.

The effects of puff frequency and the presence of water in the bowl on NFDPM and nicotine are shown in Figs. 5 and 6. As shown in Fig. 5, the puffing frequency was found to be a significant factor with respect to NFDPM, while the presence of water showed no discernible impact at either puffing frequency. In contrast to this, Fig. 6 shows that the nicotine content is

strongly affected by the presence of water in the bowl, but not by the puffing frequency. It appears that the water preferentially strips a large fraction of the water-soluble nicotine, though since the water affects not only the smoke aerosol, but also the combustion process via the previously noted bubbling-induced “drumming effect”, the conclusion must remain tentative.

### 3.4. Metals profile

A metals analysis of the filter pads for two standard argileh smoking sessions was performed using ICP, and the results for those considered biologically active are shown in Table 3, except for mercury, which was not determined. For comparison, ranges of typical values are also given for cigarette smoke (Hoffmann and Hoffmann, 2000). As shown, the levels of chromium, cobalt and lead are orders of magnitude greater than produced by a single cigarette.

Arsenic, beryllium and chromium are listed by IARC as Group 1 (known human) carcinogens, while cobalt and lead are listed as Group 2B (possible human) carcinogens (Smith et al., 1997, 2001). Nickel, depending on its form, appears on both the Group 1 and Group 2B lists.

**TABLE 3** Heavy metals identified in argileh smoke condensate of a standard 100-puff smoking session (ng)

	Argileh	Cigarette
Arsenic	165	40-120
Beryllium	65	300
Nickel	990	ND-600
Cobalt	70	0.13-0.2
Chromium	1340	4-70
Lead	6870	34-85

Values found in a recent review (Hoffmann and Hoffmann, 2000) of previous cigarette smoke studies shown for comparison.

## 4. Discussion

This study was undertaken to address the dearth of information regarding the composition of argileh smoke and to highlight methods and directions for further investigation. A smoking machine was designed and smoke from an argileh fueled with charcoal and loaded with 10 g of *mo'assel* tobacco mixture was generated using puffing parameters selected to approximate those of argileh smokers. The importance of the argileh water was tested by including a condition where no water was present in the bowl. Limitations of the study include the potential that the puffing parameters may not be representative of argileh smokers and the possibility that varying the charcoal application schedule may influence the results.

The results are summarized in Table 4. While the nicotine produced in a standard smoking session is of similar magnitude to what would be found in a single cigarette, the NFDPM is one to two orders of magnitude greater; that is, a single standard argileh smoking session produces as much “tar” as 20 low-tar cigarettes. This interpretation, however, must be taken with caution, as the composition of the NFDPM is likely to be quite different than that for cigarette smoke. Considering that the maximum temperatures found in the argileh head are approximately 450 °C, which is too low to sustain combustion, and considerably lower than maximum temperatures of circa 900 °C found in cigarettes (Wakeham, 1972), it would be expected that a larger fraction of the smoke condensates of the argileh are produced by simple distillation rather than by pyrolysis and combustion, and as a result, would tend to carry considerably less of the pyrosynthesized compounds found in cigarette smoke. Studies of tobacco pyrolysis condensates have demonstrated that tumorigenicity (Wynder et al., 1958) and mutagenicity (White et al., 2001) increase with pyrolysis temperature.

It is quite likely then that the detailed chemical composition of argileh smoke will differ from that of cigarette smoke that is produced at temperatures several hundreds of degrees higher. Thus a more detailed investigation quantifying compounds of biological interest present in the NFDPM of argileh smoke is needed before any conclusions can be drawn about the potential hazards presented by the high levels of NFDPM produced in a single argileh smoking session.

The result that roughly 5 g of charcoal are consumed in a smoking session also points to the need to quantify CO in the smoke, particularly given the fact that much of a charcoal briquette burns in a fuel-rich mode, and that the gases are immediately quenched as they pass from the surface of the coal into the relatively cool tobacco mixture. On the other

hand, the particulate phase contribution of the charcoal is minimal on a mass basis.

While the results obtained thus far are valuable as first indications of the magnitudes of the nicotine, NFDPM and metals that can be expected in mainstream argileh smoke, considerable work remains to be done in order to assemble a more comprehensive picture. Apart from more detailed chemical analysis (particularly of the composition of the NFDPM) and CO quantification, the method outlined in this paper requires considerable tuning.

First, a model of a “standard smoking session” based on smoking topography field studies is sorely needed. As shown in this work, both the puff frequency and volume impact the measured TPM. Likewise, investigation into the fluid mechanics of the puffing event is also needed, particularly the degree to which an actual puff deviates from the quasi-steady assumption built into the simple smoking machine described above. In the event that smoking topography measurements indicate that a typical puff flow rate profile is not well represented by this

assumption, the on-off solenoid valve can be replaced by a digitally controlled proportional valve that will yield whatever the desired profile, and the impact of various flow profiles at constant puff volume can be quantified.

Of obvious importance in the heat transfer-driven smoke aerosol production process would be an assessment of the role of the charcoal application schedule (mass, timing, geometric configuration), which should be measured in argileh smoking topography field studies. This may be especially important with respect to highly temperature-dependent chemical reaction pathways, and the resulting composition of the smoke aerosol. Likewise, the impact of the mass of tobacco mixture, and the effect of variations in tobacco porosity

deriving from how tightly it is packed into the head is also needed. In a similar vein, the aluminium foil perforation pattern (size, number and distribution of holes) may be of significance as it will impact the path of the hot gases through the tobacco mixture.

**TABLE 4** Summary of findings—10 g of tobacco mixture, 100 3-s puffs of 0.3 l volume each (standard deviations shown in parentheses)

Condition		Rest interval (s)		
		30	15	15 water removed
Tobacco consumed	[g/session]	3.0 (0.2)	3.3 (0.3)	3.5 (0.5)
Coal consumed	[g/session]	5.2 (0.1)	4.5 (0.1)	4.5 (0.15)
Nicotine	[mg/session]	2.25	2.11	9.29
	[mg/g consumed]	0.761 (0.071)	0.669 (0.161)	2.62 (0.61)
NFDPM (“Tar”)	[g/session]	0.242	0.393	0.448
	[g/g consumed]	0.0817 (0.008)	0.120 (0.014)	0.127 (0.024)

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**POLYCYCLIC AROMATIC HYDROCARBONS,  
CARBON MONOXIDE, "TAR", AND NICOTINE IN  
THE MAINSTREAM SMOKE AEROSOL  
OF THE NARGHILE WATER PIPE**

Alan Shihadeh  
Rawad Saleh

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## Abstract

A smoking machine protocol and yields for "tar", nicotine, PAH, and CO are presented for the standard 171-puff steady periodic smoking regimen proposed by Shihadeh et al. [Shihadeh, A., Azar, S., Antonios, C., Haddad, A., 2004b. Towards a topographical model of narghile water-pipe café smoking: A pilot study in a high socioeconomic status neighborhood of Beirut, Lebanon. *Pharmacology Biochemistry and Behavior* 79(1), 75]. Results show that smokers are likely exposed to more "tar" and nicotine than previously thought, and that pyrolytically synthesized PAH are present in the "tar" despite the low temperatures characteristic of the tobacco in narghile smoking. With a smoking regimen consisting of 171 puffs each of 0.53 l volume and 2.6 s duration with a 17 s interpuff interval, the following results were obtained for a single smoking session of 10g of *mo'assel* tobacco paste with 1.5 quick-lighting charcoal disks applied to the narghile head: 2.94 mg nicotine, 802 mg "tar", 145 mg CO, and relative to the smoke of a single cigarette, greater quantities of chrysene, phenanthrene, and fluoranthene. Anthracene and pyrene were also identified but not quantified. The results indicate that narghile smoke likely contains an abundance of several of the chemicals thought to be causal factors in the elevated incidence of cancer, cardiovascular disease and addiction in cigarette smokers.

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*Keywords: Argileh; Arguileh; Narguile; Nargileh; Shisha; Hooka; Hubble-bubble; Water-pipe; Tobacco smoke*

# 1. Introduction

Studies on the chemical composition, toxicity, and carcinogenicity of cigarette smoke generated using a smoking machine are widely used to predict and understand health effects of smoking, and to compare effects of varied tobacco blends, delivery methods, and puffing behavior. They complement in-vivo and epidemiological studies of smoking and have contributed significantly to a better understanding of cigarette smoke toxicity and carcinogenicity (Hoffmann et al., 2001) and to generating the evidence needed for anti-tobacco policies and action. More than 4800 compounds, including 69 carcinogens, have been identified in cigarette smoking machine studies that span a period of more than 40 years (Hoffmann et al., 2001). In contrast, we have been able to locate only four studies (Rakower and Fatal, 1962; Hoffman et al., 1963; Sajid et al., 1993; Shihadeh, 2003) of the chemistry of narghile smoke in the open English-language literature, in which a comparatively small range of chemical compounds were investigated. In none of these studies are CO or PAH, two major toxic agents in tobacco smoke, quantified using relevant narghile smoking parameters.

This relative paucity in research on narghile smoke chemistry cannot be attributed to the insignificance of the topic. The narghile water-pipe is prevalent in Southwest Asia and North Africa, and in recent years has shown a sharp rise in popularity particularly among young people (Chaaya et al., 2004). National and local surveys in Kuwait (Memon et al., 2000), Egypt Mohamed et al., 2003), Syria (Maziak et al, 2004), and Lebanon (Shediak-Rizkallah et al., 2002; Jabbour, 2003) have found that 20-70%, and 22-43% of the sampled populations has ever smoked or currently smokes the narghile, respectively. Anecdotal evidence in the form of newspaper reports (e.g. McNicoll, 2002; Landphair, 2003; Edds, 2003; Gångloff, 2004) and “hookah bar” advertisements in college papers and on the internet suggest that water-pipe smoking is catching on in North America and Europe as well.

With a dearth of scientific studies, researchers, public health officials, and the general public have had little data to assess the potential hazards of water-pipe smoking. Even so, a widespread perception among smokers, and even physicians (Kandela, 1997), is that the water through which the smoke bubbles filters the toxic components, rendering the practice considerably less harmful than cigarette smoking.

While it is tempting to do so because of the sheer volume of available cigarette smoke data, the water-pipe is so different from the cigarette that data on smoke composition and toxicity cannot be extrapolated from the later to the former. Apart from the obvious differences in smoke delivery, involving long passages and a water bubbler in the case of the narghile, the smoke aerosol generation

process is also considerably different. Whereas the cigarette involves a self-sustaining combustion of roughly 1 g of dried and shredded tobacco in several puffs with volumes on the order of tens of ml, the argileh utilizes an external heat source (charcoal) to largely devolatilize typically 10-20 g of heavily flavored and hydrated tobacco paste (in the case of *mo'assel* tobacco; see Shihadeh (2003) for a description of narghile components and typology) with puff volumes an order of magnitude greater and with characteristic tobacco temperatures several hundreds of degrees Celsius lower. Thus there is a need for developing research methods and smoke composition data specific to the narghile water-pipe.

Our previous work (Shihadeh, 2003) on the mainstream narghile smoke chemistry showed that it contains significant amounts of "tar" and nicotine, and that even for the same total smoked volume, the results varied considerably depending on the machine puffing regimen used. We also found that while the "tar" of a single narghile smoking session was startlingly high, typically two orders of magnitude greater

than that produced from a single cigarette, it was likely to have a different composition due to the much lower temperature of the tobacco in the narghile. We anticipated therefore that the proportion of pyrosynthesized 4- and 5-ring PAHs responsible for much of the carcinogenicity of "tar" should be considerably lower than for cigarettes. It was also found that approximately 5 g of charcoal were consumed in the course of a single smoking session, suggesting the possibility of large quantities of carbon monoxide being delivered to the smoker.

The current study follows up on these issues. The objectives were to (1) provide new data for "tar" and nicotine using an updated, and considerably more intense, puffing model which was derived from precise smoking topography measurements of 52 smokers in the field, (2) quantify the amount of CO delivered to the smoker, and (3) quantify PAH in the particulate phase so as to allow an informed interpretation of the high quantities of "tar" with respect to carcinogenic PAH compounds.

## 2. Materials and methods

### 2.1. Smoking machine

A first-generation digitally programmable smoking machine was developed for this study (see Fig. 1). The programmable inputs to the smoking machine include puff duration, flow rate, interpuff interval, and total number of puffs. The smoking machine relies on a high-flow vacuum pump which is modulated by an electronic proportional control valve. The control valve signal is generated using feedback control provided by a PC-based data acquisition and control (DAQ) system. The feedback is provided by an electronic mass flow meter whose output signal is constantly sampled and recorded in a look up table containing valve control voltages and the resulting flow rates. Prior to the first smoking session, a calibration program is run which increments the valve control voltage signal from zero to the maximum value, thus initializing the lookup table. Once a smoking session is started, the initial values in the table are dynamically updated as flow conditions change (e.g., as pressure drop

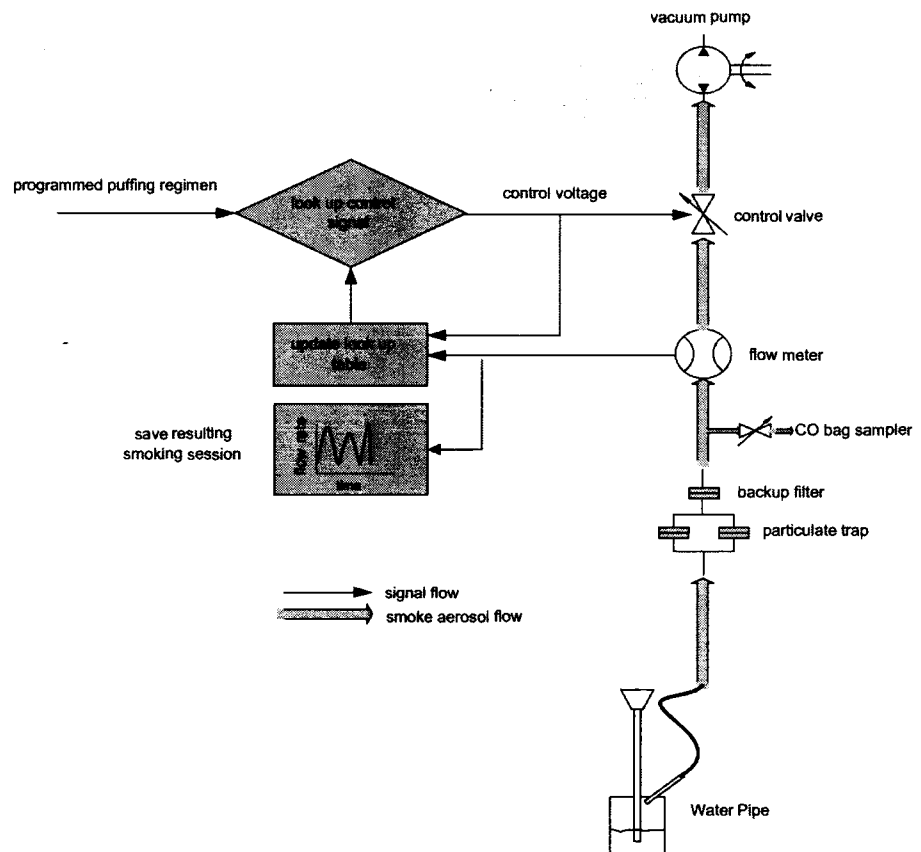


FIG. 1. Schematic of the digital smoking machine.

across filters increases, or as filters are replaced). We have found that this control scheme provides less than 1% error in the session cumulative puff volume.

The smoke aerosol was split into two streams immediately downstream of the narghile hose outlet and each stream drawn through a single 47 mm Gelman type A/E glass fiber filter pad before being re-combined. Each pad was held in a transparent polycarbonate holder, also manufactured by Gelman. This two parallel-filter configuration required eight sets of filters (i.e. seven filter changes during each smoking session) to limit the particulate loading to circa 100 mg per filter. (ISO 4387:1991 specifies that up to 150 mg of tobacco smoke condensates may be collected on a 47 mm glass fiber filter pad.) A secondary filter was placed downstream of the 2-to-1 junction and weighed before and after each run to ensure that there was no breakthrough. We also experimented with single and quadruple parallel filter configurations (also with a total of 16 filters per smoking session to limit loading), and found that the two filter set up was most convenient to use given the on-line filter changes during a smoking run. Filter holders were equipped with quick-release polypropylene fittings to help ensure that the operator could change the filters in the span of the 17 s interpuff interval.

To limit evaporative losses when the filters were removed from the smoking machine, the downstream fitting of each filter holder had a spring-loaded automatic shutoff valve mechanism that immediately closed when the holder was removed from the machine. The upstream side was simply manually sealed with a rubber end cap immediately upon removal. We did not fit an automatic shutoff valve on the upstream side as this would likely have caused particle transport losses in the narrow passages of the valve.

For CO determination a fraction (circa 9% vol) of the smoke aerosol flow was sampled from the main flow smoke path through a critical orifice

by a miniature sealed diaphragm pump that exhausted into a 10l tedlar grab sample bag (SKC, Inc. #232-08). The pump was activated during each puff by the DAQ system via a digital solid state relay.

## 2.2. Machine smoking protocol

Except for the changes to the smoking regimen, filter replacement schedule, and coal application method discussed below, all other procedures given in Shihadeh (2003) were followed, covering aluminum foil preparation, bowl water changes, tobacco type, quantity, storage, and homogenization, and narghile preparation.

### 2.2.1. Smoking regimen

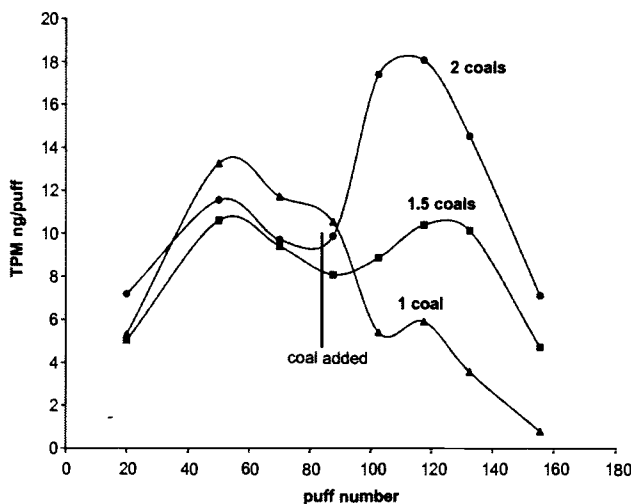
A smoking topography study of 52 volunteer smokers in a popular café in the Hamra neighborhood of Beirut was undertaken to determine realistic smoking parameters for the smoking machine study. The study made use of an electronic smoking topography instrument to record narghile flow rate as a function of time. Based on time-segmented analyses of the recorded smoking sessions, we derived a steady periodic smoking model of the "average" smoking session, consisting of 171 puffs, each of 0.53 l volume and 2.6 s duration. The interpuff interval was 17 s. The smoking topography instrument and the 52 smoker pilot study are further described in Shihadeh et al., 2004a,b, respectively.

### 2.2.2. Coal application

Because the new smoking regimen was considerably more intense than the previously used 100 puff regimen, we found that the previously sufficient single quick-light charcoal disk (Three Kings brand, Holland) was consumed well before the end of the smoking session, rendering the last 20 puffs nearly smoke-free. Smokers normally add coals during a smoking session to subjectively maintain the "strength" of the smoke. We performed several experiments

with varying coal application schemes to identify one which gave realistic yet diminishing smoke yields toward the end of the smoking session, as was commonly observed in the field. To do so, we monitored the tobacco burn fraction in the head, the puff-resolved total particulate matter (TPM), and visually inspected the burned tobacco charge at the end of the session.

Fig. 2 shows typical TPM data collected for three coal application schedules involving 1, 1.5, and 2 charcoal disks. The 1.5 and 2 coal cases were begun with a single coal disk which was augmented at the 80th puff with an additional pre-lit half or whole coal disk. Half disks were made by running whole disks through a high-



**FIG. 2.** Evolution of interval-average TPM with puff number for a variety of coal application schedules. All schedules started with a single coal disk; at the 80th puff, and additional half or whole coal was added. The 1.5 coal schedule can be seen to provide relatively uniform TPM production throughout the smoking session and was used in this study.

speed band saw. As shown, smoke production for the single coal case dropped precipitously after 100 puffs, whereas the 2-coal case over-produced in the second half of the session, leading to an excessively burnedout (i.e. entirely blackened) tobacco charge by the session s end. The 1.5 coal condition appeared to give a relatively consistent smoke production rate throughout the smoking session, while leaving a part of the tobacco charge relatively moist, as is normally the case with real smoking. To further tune the 1.5 coal procedure, the timing of the second coal application was moved from the 80th to the 105th puff, yielding somewhat lower tobacco burn fractions close to the median 46% burn fraction found in our previously reported pilot field study of 28 smokers (Shihadeh, 2003). Table 1 provides a summary of the TPM and tobacco burn fractions for the four variations. Condition C was used for the remainder of the study.

It should be noted that these quick-light charcoal disks are commonly used in narghile smoking and are invariably sold wherever narghile tobacco is sold. Smokers rely on them when convenience dictates, since the more traditional charcoal requires a small grill and longer lighting times. Nonetheless, we estimate that while self-lighting charcoal disks are used in an important fraction of narghile smoking sessions, the majority of narghile smoking, especially in restaurants and cafés, is done using the traditional charcoal, which is inherently heterogeneous in size and shape. In the interest of reproducing experiments and simplifying the procedures, we have used the standard quick-lighting charcoal disks.

**TABLE 1** Effect of coal quantity and timing of second application on tobacco burned and TPM generated

Schedule	Coal disks	Second application puff number	Tobacco burned, g	TPM, g
A	1	N/A	3.78	1.15
B	1.5	80	4.90	1.64
C	1.5	105	4.66	1.38
D	2	80	5.08	1.92

Schedule C was used in this study.

### 2.2.3. Filter changes

As mentioned above, eight pairs of filters were used during each run to prevent filter overloading. The filter pairs were changed at 40, 60, 80, 95, 110, 125, 140, and 171 puffs, yielding an average loading of 90 mg TPM per filter.

## 2.3. Chemical analysis

Thirty-two replicate smoking sessions were conducted. For every smoking run, the weight of the loaded, foil-wrapped head was recorded before and after each smoking run, as were the filter holders and the coal disks. TPM was determined as the total weight increase of the 16 filter holder assemblies.

To determine water content, the 16 filter pads were combined in a 250 ml bottle and stirred for 20 min with 50 ml of ethanol. 5 ml of the resulting solution was then added to the reaction chamber of a modified KF apparatus (Aquametry II, Barnstead-Thermolyne). Using filter blanks with known quantities of water we found that this extraction procedure was quantitative to the accuracy of the KF instrument. Water content was determined in this fashion for five replicate smoking sessions.

To quantify nicotine, the 16 filter pads for each smoking session were combined and extracted in ethyl acetate and toluene and analyzed by GC-MS according to standard methods (Siegmund et al., 1999). Nicotine was determined in this manner for five replicate smoking sessions. "Tar" or nicotine-free dry particulate matter (NFDPM) was then calculated for the aggregate data by subtracting the average water content and the average nicotine from the average TPM found. Because the TPM and water content were found to be three orders of magnitude greater than the nicotine, the NFDPM was essentially equal to the DPM.

To quantify PAH, the method described by Brunnemann et al. (1994) was adopted with

some modifications. The 16 filter pads were combined and extracted using sonication in a solution of 10% dichloromethane in acetonitrile. The resulting solution was concentrated by evaporation, and cleaned by elution with 80:20 hexane dichloromethane mixture through a silica gel column treated with sodium sulphate. The mixture was then evaporated to dryness under nitrogen, and re-dissolved in acetonitrile. The acetonitrile solution was then analyzed by HPLC (Hewlett Packard, Model 1100) coupled to a diode-array UV detector. Chromatographic separation was achieved using a 25 cm x 4.6 mm C18 column, with a solvent program beginning with a 50% acetonitrile-water mixture for 3 min, followed by a 10 min linear ramp to 100% acetonitrile, and ending with an additional 25 min at this condition. PAH were identified by the recorded spectra of the UV detector, and confirmed by standards spiking. PAH were quantified using the standard addition method with a mixture of 13 PAH: anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, fluoranthene, fluorine, indeno(1,2,3-cd)pyrene, phenanthrene, and pyrene. Quantifications were made in this manner for 10 replicate smoking sessions.

Carbon monoxide was quantified for each of five replicate smoking sessions using a calibrated electrochemical CO analyzer (Monoxor II, Bacharach Inc.) that was connected to the grab sample bag after the smoking session was terminated. A limited number of experiments were made with a non-dispersive infrared CO analyzer (Emission Systems Inc., Model 4001) to validate the measurement. Measured volume concentrations of CO were reported in units of mass by multiplying by the total drawn smoke volume and the density of the CO at ambient temperature and pressure. The initial dead volume between the sampling point and grab bag was negligible to the accuracy of the CO instrument, and was therefore excluded from analysis.

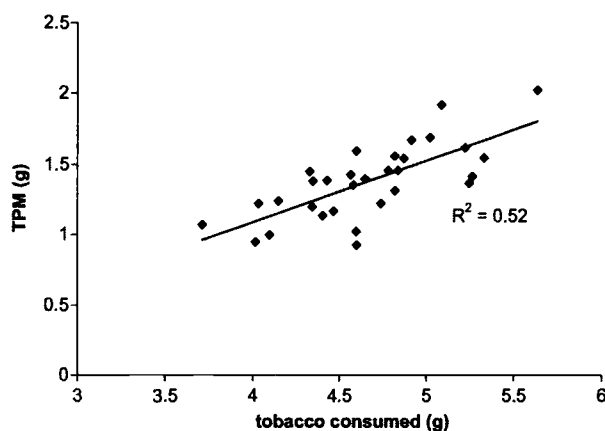


## 3. Results

### 3.1. TPM and tobacco consumed

The average TPM for the 32 replicate smoking sessions was  $1.38 \pm 0.26$  g (mean  $\pm$  standard deviation), while the average tobacco consumed was  $4.7 \pm 0.4$  g. The wide range of tobacco consumed for the 32 replicate sessions probably reflects inherent variability in handpacking the tobacco mixture in the narghile head, as well as differences in the burning history of the charcoal disk caused by the varying degrees of coal fracture, disintegration, and migration on the head which resulted from its “drumming” at the bubbling frequency.

Fig. 3 shows that TPM and tobacco consumed are linearly correlated. To account for variations across experiments, all chemical determinations were reported per g of TPM for the smoking session in question. The mean quantity of analyte per gram of TPM was then scaled by the mean TPM for the 32 replicate smoking sessions to infer the population-mean quantities for “tar”, nicotine, CO, and selected PAH of the “average” smoking session.



**FIG. 3.** TPM and tobacco consumed for 32 replicate smoking sessions consisting of 171 puffs of 0.53 l volume, 2.6 s duration, and 17 s interpuff interval.

### 3.2. Moisture

Average water content determinations for five replicate smoking sessions was found to be  $0.416 \pm 0.019$  g/g TPM. The mean TPM for these five smoking sessions was  $1.45 \pm 0.10$  g.

### 3.3. Carbon monoxide

Determinations of carbon monoxide for five replicate smoking sessions yielded an average of  $105 \pm 4$  g/g TPM. The mean TPM for these five smoking sessions was  $1.36 \pm 0.11$  g.

### 3.4. Nicotine and "tar"

The nicotine determinations for five smoking sessions yielded an average of  $2.15 \pm 0.049$  mg/g TPM. The TPM for these five sessions was  $1.36 \pm 0.21$  g. Using this percentage and that previously found for the water content, the average "tar" for the 32 sessions was calculated to be 802 mg.

### 3.5. PAH

It was possible to positively identify chrysene, fluoranthene, anthracene, pyrene, and phenanthrene in the narghile smoke condensates. Of these, only signals corresponding to chrysene, fluoranthene, and phenanthrene were well-resolved and quantifiable. These compounds exhibited average recoveries of 32%, 64%, and 93%, respectively using the extraction and clean-up method described above. The chromatograms were heavily populated with peaks possibly resulting from the various flavorings of the *mo'assel* tobacco paste. Determinations for PAHs in ten replicate smoking sessions yielded  $0.543 \pm 0.151$  lg/g TPM phenanthrene,  $0.160 \pm 0.053$  lg/g TPM fluoranthene, and  $0.081 \pm 0.044$  lg/g TPM chrysene. The mean TPM for these ten sessions was  $1.36 \pm 0.22$  g.

## 4. Discussion

Using a smoking model based on detailed smoking topography field measurements, new data have been generated on the composition of smoke from a narghile loaded with 10 g of *mo'assel* tobacco mixture, and fueled with 1.5 quick-lighting charcoal disks applied in such a manner as to give realistic aerosol production rates and tobacco burn fractions. As expected, the updated smoking model, which prescribes a more intensive smoking regimen than used in our earlier study, resulted in significantly higher quantities of nicotine and “tar”. Further, PAHs and CO, which have not been previously reported for realistically generated narghile smoke aerosols, have been quantified. Limitations of the study include the potential that the coal type and application schedule is not representative of real smoking, and that few PAH compounds could be quantified with confidence.

The results are summarized in Table 2. In comparison to our previous study, the amount of tobacco consumed, the nicotine, and “tar” have increased substantially, affirming the importance of the smoking regimen when investigating the chemistry of tobacco smoke aerosols. While the

**TABLE 2** Substances found in argileh smoke for 171-puff smoking session. Arithmetic mean reported for 5 replicate machine smoking sessions (10 smoking session for PAH determinations). Previous results using 100, three-second puffs as well as cigarette smoke data are shown for comparison

	Current study <sup>a</sup>	Shihadeh (2003) <sup>b</sup>	Single cigarette
Tobacco consumed, g	4.7	3.0	
“Tar”, mg	802	242	1-27 <sup>c</sup> (11.2) <sup>d</sup>
Nicotine, mg	2.96	2.25	0.1-2 <sup>c</sup> (0.77) <sup>d</sup>
CO, mg	143		1-22 <sup>c</sup> (12.6) <sup>d</sup>
<b>PAH</b>			
Phenanthrene, µg	0.748		0.2-0.4 <sup>c</sup>
Fluoranthene, µg	0.221		0.009-0.099 <sup>e</sup>
Chrysene, µg	0.112		0.004-0.041 <sup>e</sup>

<sup>a</sup> Ten grams of tobacco mixture used in arghileh head, 171 2.6- second puffs of 0.53 l volume each, spaced 30 s apart.

<sup>b</sup> Ten grams of tobacco mixture used in arghileh head, 100 threesecond puffs of 0.3 l volume each, spaced 30 s apart.

<sup>c</sup> Reported ranges for commercial cigarettes, Jenkins et al. (2000).

<sup>d</sup> Arithmetic mean for 1294 domestic cigarette brands tested by FTC for 1998 (FTC, 2000).

<sup>e</sup> LGC (2002).

nicotine produced in a smoking session is of similar magnitude to what would be found in a several cigarettes, the "tar" is one to two orders of magnitude greater, as is the CO. "tar" is normally taken as an indication of the quantity of carcinogens present in the smoke of a cigarette (e.g. benzo(a)pyrene, BaP, scales linearly with cigarette smoke "tar"). However in the case of the narghile, the much lower tobacco temperatures involved (circa 450 °C versus 900 °C) imply that the "tar" composition should be skewed towards products of simple distillation rather than pyrolysis and combustion. Indeed, based on the figures given in Table 2, phenanthrene per mg "tar" is roughly 30 times greater in cigarette smoke than in narghile smoke, indicating that with respect to pyrosynthesized PAH, cigarette "tar" is more potent. The same may not be true for other carcinogenic compounds, such as tobacco specific nitrosamines, which are already present in the tobacco.

Notwithstanding the lower concentration per mg of tar, the three PAH quantified in the smoke, all 3- or 4- ring compounds, were found in quantities many times that of a single cigarette. Chrysene is a tumor initiator while fluoranthene and pyrene (identified but not quantified) are co-carcinogens (Surgeon General, 1979). The fact that 5-ring PAHs such as the notorious BaP were not detected in this study may be due to masking by co-eluting compounds in the complex narghile smoke matrix, or may indicate that they are present in quantities below detectable limits. Further development of the PAH quantification procedures are needed to firmly resolve this question, though it is generally accepted that BaP is present wherever combustion-originating PAH compounds are found. Furthermore, recent work on PAH formation from catechol pyrolysis has shown that BaP formation kinetics exhibit pseudo-first order Arrhenius parameters very close to those of chrysene (Ledesma et al., 2002), indicating that since chrysene is found in abundance, conditions in the narghile are

favorable for the formation of BaP. We would thus caution against concluding that the absence of BaP and other carcinogenic 5-ring PAH in Table 2 means that they are absent from narghile smoke. Chrysene to BaP quantities in cigarette "tar" are typically 2-3:1. In addition, if the PAH are synthesized during the smoking session their presence strongly suggests that the precursor benzene exists in the vapor phase of the smoke as well.

The high CO reported in Table 2 is likely a result of the charcoal combustion. Carbon monoxide is considered a major causative agent in cardiovascular disease among smokers (Hoffmann et al., 1997). It is worth noting that the CO to nicotine ratio of narghile smoke is approximately 50:1, compared to 16:1 for cigarettes. Thus if narghile smokers titrate for nicotine as do some cigarette smokers, they can be exposed to significantly greater CO in the course of seeking nicotine satisfaction. The same is true for the PAHs; chrysene for example yields a 40 ng/mg nicotine ratio compared to 2-3 ng/mg for cigarette smoke. Thus smokers who switch from cigarettes to narghile smoking under the impression that the water filters the smoke may actually expose themselves to higher quantities of PAH and CO.

Taken together the limited data to date already indicate that narghile smoke likely contains an abundance of several of the toxicants that are thought to render cigarette smokers more prone to cancer, heart disease, and addiction.

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## Abstract

A pilot study of narghile water-pipe smokers in a cafe in the Hamra neighborhood of Beirut, Lebanon, was conducted to develop a preliminary model of narghile water-pipe smoking behavior for use in laboratory smoking machine studies. The model is based on data gathered from smoking sessions of 30 min or longer duration from 52 smoker volunteers using a differential pressure puff topography instrument, as well as anonymous visual observations of 56 smokers in the same cafe. Results showed that the “average” water-pipe cafe smoking session consists of one hundred seventy-one 530-ml puffs of 2.6-s duration at a frequency of 2.8 puffs/min. The implications of this comparatively high-intensity puffing regimen on the production of toxic smoke constituents are discussed.

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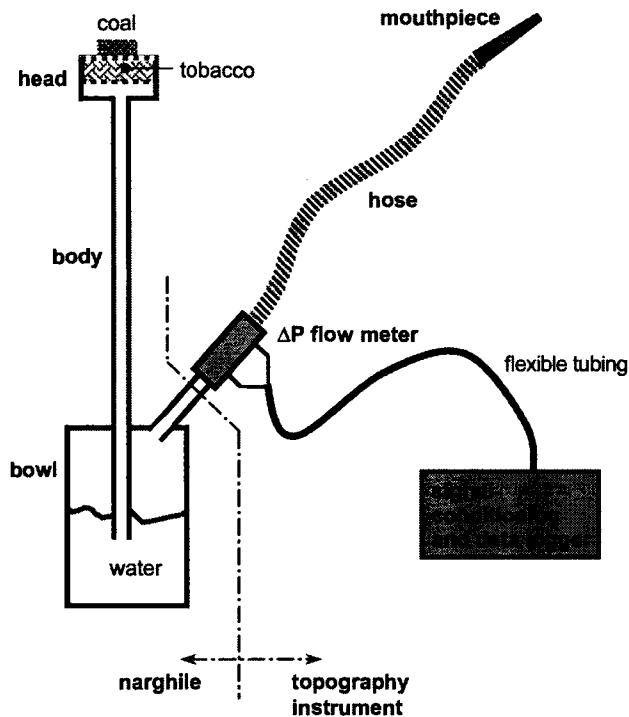
*Keywords:* Topographical model; Narghile water-pipe; Smoking; Beirut

*Abbreviations:* STI, smoking topography instrument.

## 1. Introduction

A sharp rise in the popularity of the narghile water-pipe has been noted in recent years (Chaaya et al., 2004). National and local surveys in Kuwait (Memon et al., 2000), Egypt (Israel et al., 2003), Syria (Maziak et al., 2004), and Lebanon (Shediak-Rizkallah et al., 2002; Jabbour, 2003) have found that 20–70% and 22–43% of the sampled populations has ever smoked or currently smokes the narghile, respectively. Anecdotal evidence in the form of newspaper reports (e.g., McNicoll, 2002; Barnes, 2003; Landphair, 2003; Edds, 2003; Gangloff, 2004) and “hookah bar” advertisements in college papers suggests that narghile smoking is catching on in North America and Europe as well.

The new appeal of the narghile water-pipe, until recently considered the domain of older men in Southwest Asia and North Africa, appears to be correlated with the marketing of an array of fruit-flavored tobacco mixtures, which list “molasses” as an ingredient, and which burn with a strong aroma of caramelizing sugar. Cafes and restaurants offering narghile water-pipes as a form of entertainment to young women and men have mushroomed in recent years in the Middle East and North Africa and come in the context of a broad commercialized revival of regional customs. In these cafes, and in printed and televised ads, wait staff can often be seen wearing costumes that purport to conjure the authentic atmosphere of the past, in which narghile smoking presumably flourished.



**FIG. 1.** Schematic of the narghile water-pipe, shown with the topography instrument attached. The hose and mouthpiece of the topography instrument are identical to the originals. Not to scale.

Fig. 1 illustrates the main features of the narghile water-pipe. The head, body, bowl, and hose are the primary elements from which a narghile is assembled. When a smoker inhales through the hose, a vacuum is created in the headspace of the water bowl sufficient to overcome the small (typically 3 cm H<sub>2</sub>O) static head of the water above the inlet pipe, causing the smoke to bubble into the bowl. At the same time, air is drawn over and heated by the coals, with some of it participating in the coal combustion, as evinced by the visible red glow that appears during each puff. It then passes through the tobacco mixture (typically, 10–20 g are loaded), where due to hot air convection and thermal conduction from the coal, the mainstream smoke aerosol is produced.

Despite its long history and recent revival, there have been few studies on narghile smoking, and recognized methods and instruments specific to its study have yet to be developed. Recent smoking machine studies (Shihadeh, 2003) at the AUB Aerosol Research Lab have shown that the quantities of tar and nicotine delivered at the mouthpiece strongly depend on the puffing parameters used, even when the total drawn volume is held constant. It was found, therefore, that toxicological assessment of narghile smoking requires models of smoking behavior based on studies of smokers. To the best of our knowledge, no previous detailed smoking topography data have been collected from which a model can be derived.

The objectives of this study were to provide data that can be used to guide the design of smoking topography studies and to derive a first approximation of “average” narghile smoking parameters, such as puff volume, duration, and frequency for the purpose of programming laboratory smoking machines used in toxicological assessments, as is commonly done with cigarette testing, where a fixed frequency, duration, and puff volume smoking regimen is used to generate the smoke sample. To do so, we conducted a field study using a portable smoking topography instrument (STI) at a busy cafe near the American University of Beirut (Beirut, Lebanon), where the narghile is served. Our work has focused on the cafe because it provides a convenient natural setting for making topographical measurements for many smokers and likely represents a large fraction of narghile consumption, particularly for the young narghile smokers, who have taken up the habit in recent years. Other smoking settings, such as the home and public outdoor places, also likely account for a large fraction of narghile consumption, possibly with varied smoker characteristics (e.g., gender, age, and prior smoking experience), which could affect topography. These settings are not covered in the present study.

## 2. Methods

### 2.1. Study design and procedures

The study was conducted in two phases. In the first, a portable STI was attached to the narghiles of 52 smokers in a cafe, prior to commencement of smoking, and measurements of flow rate versus time were made for typically 30–40 min of unsupervised smoking. A limited number of measurements were made in which the entire smoking sessions were sampled. Using the data compiled from the first 30 min of smoking, a time-resolved smoking model was derived from which a whole smoking session of a given duration could be inferred. We assumed that the 30-min minimum sampling duration would provide a sufficiently representative data sample to determine the mean puff duration, flow rate, and frequency for a given smoker, while also allowing a greater number of smokers to be sampled in the time available for this pilot study.

This assumption was tested by tracing the cumulative and moving averages of each topographical parameter over time for the first 30 min of smoking, averaged over the 52 smokers. In this way, we could (1) elucidate temporal patterns of the smoking ritual, (2) directly assess how the results would have differed had we sampled each smoker for a shorter time, and (3) extrapolate trends in time to predict cumulative mean puff parameters for sessions longer than 30 min in duration. Item 3 was tested by comparing the extrapolated and recorded data for those smoking sessions sampled longer than 30 min. Nemeth-Coslett and Griffiths (1984) and Morgan et al. (1985) followed a similar approach of tracking the evolution of group mean puffing parameters for cigarette smokers in a laboratory and natural setting, respectively.

When a cafe customer ordered a narghile, the food server notified the field worker, who then proceeded to recruit the customer as a volunteer in the study. If consent was obtained, the field worker attached the STI upon delivery of the narghile. The methods used were in compliance with the Declaration of Helsinki and involved no additional risk to the smoker. Smokers were instructed to smoke as they normally would and informed that the field worker would return after some time to pick up the STI, although the field worker could be summoned earlier through the food server. The STI was left with the smoker for typically 30–40 min of unsupervised smoking in the cafe. In most cases, the smoker had still not finished smoking, and the collected data thus represented partial smoking sessions. Because the STI was physically unobtrusive (placed under the table, out of sight) and did not require any modification in smoking method, we expected that the recorded smoking sessions closely resembled the “natural” smoking behavior of the smokers in this common setting. A total of 52 smokers were sampled in this fashion. In addition to age and gender, volunteers were asked whether they sensed any differences in smoking or had any complaints in connection with the use of the STI.

The second phase of the study was conducted to determine the mean total smoking session duration by visually observing 56 smokers in the same cafe. Following the approach of Chapman et al. (1997), observations were conducted randomly without the smokers' knowledge. Using a stopwatch and a table map of the cafe, the times corresponding to the first and last puff of each smoker were recorded with an estimated accuracy of 2 min by two field workers observing the same smokers from a distance. Typically, 3–5 smokers were tracked simultaneously. No contact was made with the smokers before or after the smoking sessions, and the age and gender of the smokers were therefore assessed by best estimate of the field workers. Combined with the detailed puff topography statistics of the first phase, a complete description of the average smoking session could thus be attained from this preliminary work.

## 2.2. Instrumentation

The STI was designed for the pulsating, high flow rate of the narghile. It utilizes a differential pressure obstruction meter (Novamatrix Medical Neonatal Sensor) and pressure transducer. Pressure transducer voltage is digitized and recorded on a portable data logger at a rate of 5 Hz and is periodically downloaded to a PC for processing. The entire apparatus fits in a small tool box and weighs approximately 2 kg.

As shown in Fig. 1, the sensor is incorporated into a typical narghile hose at its point of connection with the water-pipe, far from the mouthpiece. As such, attachment of the sensor does not impose any modification in the smoking method. Unlike the cigarette-holder-utilizing topography systems now in use, the taste and feel—both in the fingers and on the lips—of the smoking device remain unchanged.

Because the flow sensor is attached to the STI hose, field data collection requires replacing the smoker's original hose at the beginning of the smoking session. Except for the presence of the

flow sensor, the STI hose and mouthpiece are identical to those in use in the cafés.

The logged data, consisting of transducer voltage versus elapsed time, is processed using software that reads the pressure transducer signal and locates the timings corresponding to the beginning and end of each puff. Puff events are defined by deviation from the zero voltage plus a tolerance value (usually equal to the resolution of the data logger), and various user-input tolerances (e.g., minimum time separation between two puffs greater than 0.1 s) exclude artifacts.

Having determined the beginning and end timings of a given puff, the instantaneous and mean flow rate between these times are calculated using an experimentally derived calibration curve of transducer voltage versus flow rate. The calibration is performed by acquiring data from the topography instrument while it is attached to a typical argileh that has been prepared for smoking, in accordance with the methods given in Shihadeh (2003). The transducer voltage is plotted against the output signal of a calibrated digital mass flow meter ( $\pm 1\%$  accuracy), while sweeping a range of flow rates from 2 to 20 standard liters per minute.

Each individual puff's volume is then calculated as the mean flow rate during the puff multiplied by the elapsed time from puff beginning to end. The data from the puff events are stored in an array from which the total number of puffs, the mean puff volume, duration, and puff frequency are calculated for a given smoking session. Maximum error for any topography parameter is less than 5% of the reading. The STI and its testing are described in more detail in Shihadeh et al. (2004).

## 2.3. Calculation procedures and data analysis

To derive a fair representation of smoking session dynamics from STI recordings of

differing lengths, the first 30 min of each recorded session were used to calculate the cumulative and moving average puff volume, duration, and frequency. The first 30 min were discretized into 18 time intervals for this purpose, and the puff parameters calculated for each interval and smoker were then averaged over the 52 smokers to arrive at a time-resolved aggregate model of the first 30 min of smoking.

For each of the 18 time intervals, the arithmetic average puff volume, puff duration, and puff frequency were calculated for each smoker, in accordance with the equations given in Appendix A. The average flow rate in each time interval was calculated as the total drawn volume during that interval, divided by the sum of the puff durations over the interval. It should be noted that this definition of mean flow rate is not necessarily equal to the mean of the individual puff flow rates. The former is a preferable definition because it weighs the mean flow rate by puff volume, rather than treating all puffs equally.

## 2.4. Participants and setting

The field study was conducted from December 2002 through May 2003 at a busy cafe adjacent to the American University of Beirut in Beirut, Lebanon. The cafe has an estimated capacity of 150 persons and is frequented predominantly by young adults, male and female. Along with light food, it offers narghiles of various tobacco flavors on the menu, for a price of 8000–10,000 LL (approximately US\$5–7). The great majority of narghiles served are of the common *mo'assel* type (see Shihadeh, 2003, for narghile typology). The relatively high price of the narghile at this cafe, as well as its proximity to the American University of Beirut, an exclusive private university whose yearly tuition is comparable to the average yearly family income in Lebanon, suggests that the population sample was likely skewed towards the upper income stratum of Beirut.

Both phases of the study were carried out between 2000 and 0100 h, in the same cafe, and usually on the weekend (Friday–Sunday).

## 3. Results

### 3.1. Participant pool

The 52 volunteers in the puff topography study consisted of 14 female and 38 male smokers, with a median age of 21 years and an interquartile range of 4.75 years. More than 85% of the approached candidate volunteer smokers were willing to have the STI attached to their narghiles and participate in the study. On three occasions, volunteer smokers complained of a residual flavor in the pipe from a previous smoking session and aborted the test shortly after starting. The data from these sessions were not tabulated. Other than these instances, no volunteer smoker noted any sensory difference from normal narghile smoking, and none aborted the test. After each day of data collection, during which typically 4–5 smoking sessions were recorded, the STI was left overnight connected to a filtered compressed air line to reduce build up of the smoke particulates from day to day.

Those anonymously observed for the total smoking time consisted of 16 female and 38 male smokers, based on visual appearance to the field workers. Because no contact was made with the smokers, we cannot be certain that the age group for this phase of the study matched that of the STI study group, although by best estimate of the field workers, the age distribution appeared to be the same. The observations were conducted in the same cafe and during the same hours as the measurements with the STI, but on different days.

### 3.2. Aggregate puff parameter statistics

Table 1 shows the 52 smoker cumulative mean puffing parameters for the first 30 min of smoking. The mean puff duration of 2.6 s is comparable with the range of 1–3 s, while the mean puff volume of 530 ml is an order of magnitude greater than the range of 42–70 ml previously reported for cigarette smokers over a wide range of smoking conditions and cigarette types (Djordjevic et al., 1997; McBride et al., 1984; Kolonen et al., 1991, 1992a,b). The puff volumes associated with the narghile are so much greater than those of cigarettes that a single narghile puff draws, a volume comparable to the cumulative volume of 335–1235 ml for an entire cigarette (Kolonen et al., 1991, 1992b; Corrigan et al., 2001). The mean interpuff interval (IPI) of about 15 s falls just under the previously reported range of 15.4–24.4 s for cigarette smokers (McBride et al., 1984; Kolonen et al., 1991). Differences in puffing parameters between male and female smokers were not statistically significant at the 90% confidence level.

The large IPI standard deviation is indicative of the highly sporadic nature of the smoking ritual. This likely results from the social nature of cafe smoking: Smokers are normally in the company of others and are engaged in conversation, as well as eating.

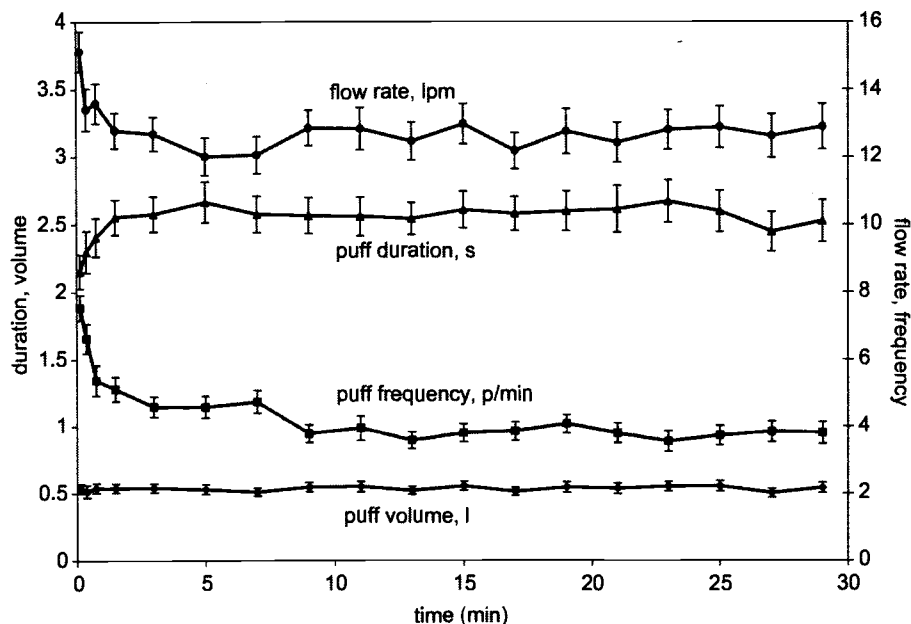
**TABLE 1** Smoker-averaged puffing parameters averaged over the first 30 minutes of smoking

N = 52	Mean	Range	S.E.M.
<i>Puff volume (l)</i>			
Mean	0.53	0.15–1.22	0.03
Maximum	1.06	0.27–1.86	0.05
Minimum	0.14	0.03–0.63	0.01
S.D.	0.19	0.04–0.42	0.01
<i>Flow rate (lpm)</i>			
Mean	12.46	5.61–23.79	0.48
Minimum	6.43	3.06–22.03	0.43
Maximum	20.00	7.94–28.98	0.64
<i>Puff duration (s)</i>			
Mean	2.60	1.21–4.74	0.12
Minimum	0.85	0.60–2.00	0.04
Maximum	5.00	1.80–10.60	0.25
S.D.	0.83	0.28–1.86	0.05
<i>Interpuff interval (s)</i>			
Mean	15.48	6.94–54.30	1.24
S.D.	19.60	6.96–55.74	1.66
<i>Puff frequency (puff/min)</i>			
Mean	3.95	1.07–6.64	0.21

### 3.3. Time-resolved aggregate puff parameters and effect of sampling period

The dynamics of the 52-smoker mean smoking session are illustrated in Fig. 2, where the aggregate averages (Eq. (A5)) of various puffing parameters for 18 successive time intervals are plotted over the first 30 min of smoking. As shown, the early part of the smoking session is characterized by relatively high flow rate, rapid succession puffs of short duration, which appear to correspond to a “light-off” period. The puffing frequency and the flow rate decay, while the puff duration rises to approximately steady values in approximately 8 min. It is notable that the decrease in flow rate is offset by the increase in puff duration in such a manner that the puff volume remains approximately constant from the beginning of the smoking session.

The approximately steady state reached after 8 min indicates that a significantly reduced sampling time could have been used without introducing error in the aggregate mean puff

**FIG. 2.** Interval average aggregate puff parameters (error bars  $\pm$ S.E.M.) for 52 smokers.

volume, duration, and flow rate. Analysis of time-truncated data showed that the cumulative mean puff parameters, except puff frequency, would have been the same as those reported in Table 1 had the sampling period been reduced to 10 min.

Cumulative aggregate mean puff frequency was found to decay monotonically with sampling period and, for a smoking session of duration  $T \geq 8$  min, is well represented by a linear fit

$$\bar{f} = c_0 + c_1 T \quad \text{p/min} \quad (T \geq 8 \text{ min}) \quad (1)$$

where  $c_0 = 4.78$  (4.64, 4.92),  $c_1 = -0.0322$  (-0.0395, -0.0250), and the parenthesis indicate the 95% confidence bounds on the fitted parameter.

### 3.4. Comparison of 30-min aggregate and longer smoking sessions

Inspection of the smoking sessions that were sampled longer than 30 min showed that there

was no qualitative change from the picture presented by the first 30 min of smoking. Puff frequency continued to decay, while the cumulative mean puff volume and duration remained invariant with time ( $R^2 < .01$ ).

We found that extrapolating Eq. (1) beyond  $T = 30$  min yielded results that are consistent with the cumulative puff frequencies found for the longer smoking session recordings. It can be seen in Fig. 3 that Eq. (1) falls within the 95% confidence limits of the best linear fit for cumulative puff frequency calculated for the entire duration of each smoking session of length greater than 35 min. It should be stressed that the equation represents the cumulative puff frequency calculated at various elapsed times, for the sample set of 52 smokers, up to  $T = 30$  min; it thus represents the evolution of the aggregate mean puff frequency for the entire set of smokers. The linear fit of the data shown in Fig. 3, on the other hand, is derived from the cumulative puff frequency for each smoker, calculated at the end of the STI recording, whose duration varied from one smoker to the next.

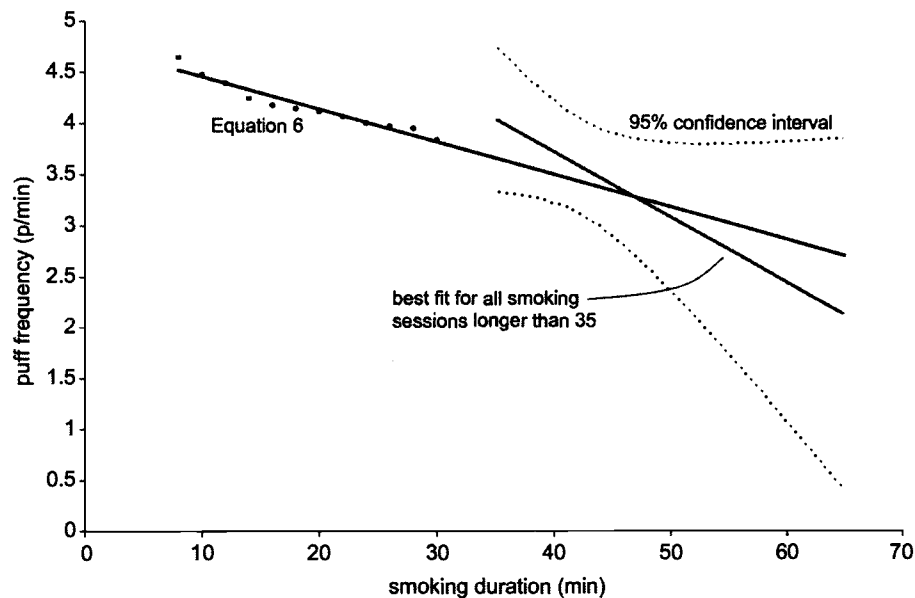


FIG. 3. Comparison of extrapolated trend in puff frequency (Eq. (1)) and best linear fit of cumulative puff frequency evaluated at the end of the STI recording vs. time for all recorded smoking sessions longer than 35 min in duration ( $n = 40$ ). Dashed lines indicate 95% confidence interval for the best linear fit.



### 3.5. Minimum sample size

Using the *t* distribution to estimate the true standard deviation of the means, the number of smoker samples required to achieve a 95% confidence interval, whose magnitude is no greater than 10% of the mean, was calculated, and the results are given in Table 2. As shown, the IPI is the limiting parameter that dictates the minimum number of smokers required to achieve a given precision interval.

The minimum sampling time per smoker needed to achieve these confidence intervals is also given in Table 2. These numbers represent the median of the minimum needed sampling times calculated for each smoker to achieve a 95% confidence with a precision of 10% of the

mean value of the parameter under question. As shown, it is impossible to meet the 10% precision criterion for the IPI because the required sampling time of 181 min exceeds the characteristic duration of an entire smoking session.

### 3.6. Total smoking time

The anonymous observation of 58 smokers yielded a mean smoking session duration of 61 min, with a 4-min S.E.M. This is comparable with the mean smoking duration of 51 min previously determined by the same technique for 28 smokers in coffee shops in Ramallah, Palestine (Shihadeh, 2003).

**TABLE 2** Samples needed for 10% precision interval at a 95% confidence level for individual smoker and aggregate puffing parameters

Puffing parameter	Puff cycles per smoker	Sampling time per smoker (min)	Required number of smokers
Volume	46	12.5	58
Duration	38	11.0	43
Interpuff interval	722	181.3	129

Median data for 52 smokers.

## 4. Discussion

This study provides a picture of smoking behavior in a particular setting, a Beirut cafe frequented by university students, derived from STI recordings of partial smoking sessions and extrapolated to an average smoking session duration, which was determined by visual observation. Its limitations include the fact that the smoking sessions were not sampled in their entirety, which would have eliminated the need to extrapolate the puff parameters. Furthermore, possible linkages to observed puffing behavior of such variables as frequency of smoking (“heavy” vs. “light” smokers), nicotine dependence, prior smoking deprivation, use of other forms of tobacco, tobacco flavor, time of day, socioeconomic status of smokers, among others, were not explored. In these respects, we do not know whether the smokers visiting the cafe in this study are representative of cafe smokers, in general, or whether, for example, our sample is skewed by disproportionate numbers of “chippers” or, conversely, nicotine-dependant smokers, whose puffing practices may differ from that of the average cafe smoker. The results of this study should therefore be taken as a snapshot of how narghiles were used in a particular place, time, and population, rather than as a general model of café smoking.

The interval- and cumulative-average puff parameters were found to be remarkably continuous in time and characterized by narrow confidence intervals, as indicated by the error bars of Fig. 2. Together, they provide a well-articulated picture of narghile smoking dynamics described by rapid succession, high flow rate puffs of short duration for the first few minutes, followed by nearly steady puffing afterwards, with a slight but continual decline in puff frequency. Except for puff frequency, all cumulative average smoking parameters would have been the same had the topography sampling time been reduced to 10 min.

Pending a wider study, the results can be used to derive a preliminary model to guide laboratory smoking machine studies of narghile toxicology, keeping the previously mentioned caveats in mind. Using Eq. (1) and the mean session smoking time of 61 min, a mean puff frequency of 2.82 puffs/min is calculated, yielding a session total of  $\bar{n} = \bar{f}T = 171$  puffs. For a whole smoking session of duration  $T$ , the effective IPI can be inferred as  $\overline{\text{IPI}} = \frac{T - \bar{n}\bar{d}}{\bar{n}} = \frac{1}{\bar{f}} - \bar{d}$ , where  $\bar{d}$  is the aggregate mean puff duration. Utilizing the aggregate mean puff duration and volume given in Table 1, an average smoking session is specified and is given in Table 3.

As noted above, this model signifies a dramatic departure from that of cigarette smoking, with its more than one order of magnitude greater puff volumes, number of puffs, and smoking session duration. It also represents a more intensive smoking regime than that used in the previously cited narghile

smoking machine study, which utilized smoking sessions consisting of one hundred 0.3-l puffs of 3 s duration, over a 60-min smoking session. A single smoking machine test was conducted using the current smoking model given in Table 3, in accordance with the methods specified in the cited study, and the total particulate matter (TPM) collected was found to be 1.10 g. This is considerably higher than the 0.40 g previously measured using the original 100 puff smoking protocol, indicating that the current model will likely yield considerably greater tar and nicotine from a single smoking session than previously reported.

**TABLE 3** Representative model of narghile café smoking for laboratory smoking machine studies

Puffing parameter	Recommended value
Number of puff cycles	171
Session smoking time (min)	61
Puff volume (l)	0.53
Puff duration (s)	2.6
Interpuff interval (s)	17

While the proposed narghile smoking model can be used in a manner analogous to the FTC method for cigarette testing, it remains to be shown that programming a smoking machine with a periodic rectangular waveform representation of a real, irregular smoking session yields representative toxicological data. The FTC smoking machine puff protocol for cigarette testing has been widely criticized in the tobacco research community as an unrealistically low-intensity puffing regimen (in terms of puff volume, duration, and frequency) that results in a significant underestimate of the delivery of various toxins to the smoker; but whether adjusting the puff parameters is enough to correct the machine studies is another question. The implications of modeling a real, irregular

smoking session as one with uniform puff volume and spacing have not been thoroughly investigated. This question may be particularly important with narghile smoking because its relatively long overall duration and many puffs could lend to significant cumulative errors. We are currently investigating this question by comparing the composition of smoke generated by “playing back” the actual recorded smoking sessions to that generated when the smoking machine is programmed with the equivalent periodic (fixed frequency, duration, and volume) sessions.

## 5. Nomenclature

### Variables

$d$	Puff duration (s)
$f$	Puff frequency (puffs/min)
IPI	Interpuff interval (s)
$n$	Number of puffs
$N$	Number of smokers
$\dot{q}$	Volumetric flow rate (l/min)
SEM	Standard error of the mean
$t$	Time
$T$	Sampling period

### Subscripts

$i$	Smoker index
eop	End of puff
sop	Start of puff

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## Appendix A

### Equations used to calculate interval average puff parameters

Mean puff parameters for smoker  $i$  over the time interval  $t_1, t_2$  were calculated as follows:

$$\bar{v}_i(t_1, t_2) = \frac{\sum_{n(t_1)}^{n(t_2)} v_{i,j}}{n(t_2) - n(t_1)} \quad \text{puff volume} \quad (\text{A1})$$

$$\bar{d}_i(t_1, t_2) = \frac{\sum_{n(t_1)}^{n(t_2)} d_{i,j}}{n(t_2) - n(t_1)} \quad \text{puff duration} \quad (\text{A2})$$

$$\bar{q}_i(t_1, t_2) = \frac{\sum_{n(t_1)}^{n(t_2)} v_{i,j}}{\sum_{n(t_1)}^{n(t_2)} d_{i,j}} \quad \text{flow rate} \quad (\text{A3})$$

$$\bar{f}_i(t_1, t_2) = \frac{n(t_2) - n(t_1)}{t_2 - t_1} \quad \text{frequency} \quad (\text{A4})$$

where for puff  $j$  and smoker  $i$ ,  $d_{i,j} = t_{\text{eop}(j,i)} - t_{\text{sop}(j,i)}$  is the puff duration, and  $v_{i,j} = \int_{t_{\text{sop}(j,i)}}^{t_{\text{eop}(j,i)}} \dot{q}_i(t) dt$  is the puff volume. It should be noted that the definition of mean flow rate given by Eq. (A3) is not necessarily equal to the mean of the individual puff flow rates. Eq. (A3) is a preferable definition of mean flow rate because it weighs the mean flow rate by puff volume, rather than treating all puffs equally. For cumulative parameters, the time interval  $(t_1, t_2)$  over which the parameter of interest was calculated began at  $t_1=0$ .

Any aggregate mean puff parameter  $\bar{p}$  for  $N$  smokers was calculated as

$$\bar{p}(t_1, t_2) = \frac{\sum_i^N p_i(t_1, t_2)}{N} \quad (\text{A5})$$

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**A CLOSED-LOOP CONTROL “PLAYBACK”  
SMOKING MACHINE FOR GENERATING  
MAINSTREAM SMOKE AEROSOLS**

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## ***Abstract***

A first generation smoking machine capable of reading and replicating detailed puffing behavior from recorded smoking topography data is presented. Unlike standard smoking machines, which model human puffing behavior as a steady periodic waveform with a fixed puff frequency, volume, and duration, this novel machine generates a mainstream smoke aerosol by automatically "playing-back" puff topography recordings. Because combustion chemistry is highly non-linear, representing real smoking behavior with a smoothed periodic waveform may result in a tobacco smoke aerosol with a significantly different chemical composition and physical properties than that generated by a smoker. The machine presented here utilizes a rapid closed-loop control algorithm coded in Labview® to generate smoke aerosols for toxicological assessment and inhalation studies. To illustrate its use, dry particulate matter and carbon monoxide yields generated using the playback and equivalent periodic puffing regimens are compared for a single smoking session by a 26-year-old male narghile water-pipe smoker. It was found that the periodic puffing regimen yielded 20% less carbon monoxide (CC) than the played-back smoking session, indicating that steady periodic smoking regimens, which are widely used in tobacco smoke research, may not produce realistic smoke aerosols.

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*Keywords:* argileh, FTC, hooka, narghile, shisha, smoke analysis, smoking machine, smoking regimen, smoking topography, tobacco smoke, waterpipe

## ***Introduction***

STUDIES ON THE CHEMICAL COMPOSITION, respirability, toxicity, and carcinogenicity of cigarette smoke generated using a smoking machine have been widely used to predict and understand health effects of smoking, and to compare effects of varied tobacco blends, delivery methods, and puffing behavior. To allow for comparisons across cigarette products, a standard testing protocol has been adopted by the U.S. Federal Trade Commission (FTC), which specifies smoking machine characteristics and a steady periodic puffing regimen of one 35-mL puff of 2-sec duration per minute. The FTC method has been criticized for specifying an unrealistically low-intensity puffing regimen (in terms of puff volume, duration, and frequency), which can result in a significant underestimate of the delivery of various toxicants to the smoker, especially for "light" cigarettes for which smokers have been shown to increase smoking intensity (e.g., puff volume) to achieve nicotine

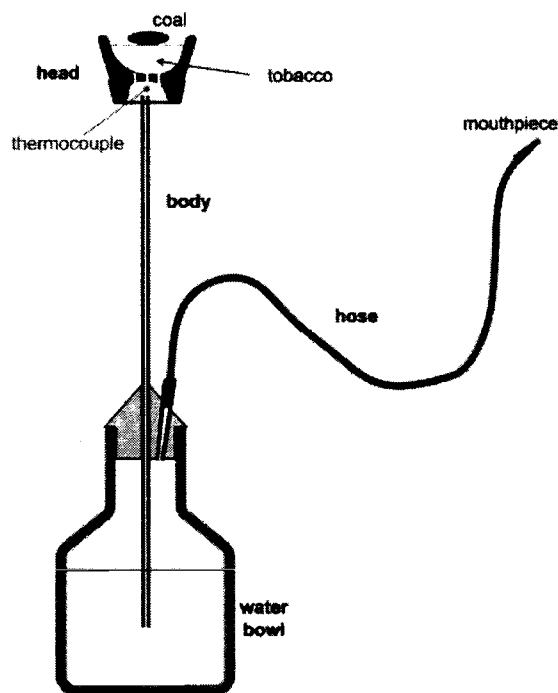
satisfaction.<sup>(1-3)</sup> When smoked using a higher intensity puffing regimen derived from smoking topography measurements of real smokers, Djordjevic et al.<sup>(3,4)</sup> found significantly higher yields of toxicants than when the cigarettes were smoked using the FTC method.

Both the FTC method and its higher intensity alternatives, however, rely on a steady periodic puffing regimen in which the puff frequency, duration, and volume are held constant over the duration of a machine smoking session. In fact, standard ISO-compliant smoking machines are not set up to smoke in any other way. In reality, puff topography measurements of cigarette smokers reveal puffing profiles that are characterized by varying puff durations, spacing, and flow rates within a given smoking session.<sup>(5-7)</sup> These intrasession puffing variations may result in varying combustion, pyrolysis, and devolatilization conditions, which can render a significantly different net smoke composition and particle size distribution than would be the case for the steady periodic smoking session in which these variations have been smoothed by averaging.

To illustrate, temperature and oxygen concentration in the combustion zone of a cigarette are dependent on the instantaneous air flow rate during puffing, as can be noticed by the glowing of the cigarette coal during each puff. Given that elementary chemical reaction rates are exponential functions of temperature, it would be fortuitous if, for a given real smoking session, the integrated average smoke composition matched that produced by a steady periodic smoking session in which all the local peaks and valleys in instantaneous flow rate have been eliminated. That is, even if the average puff duration, frequency, and volume were representative for some real smoker, there is no guarantee that these representative smoking parameters yield a representative smoke composition. For a description of the coupled

chemistry, heat transfer, and mass transfer phenomena involved in tobacco smoke production, see previous work.<sup>(8-10)</sup>

The questions arose in our ongoing study of the narghile water-pipe (Fig. 1), a tobacco smoking device popular in North Africa, West Asia, and increasingly in Europe and the United States. The narghile is commonly smoked using a heavily flavored and hydrated, shredded tobacco known as *ma'assel*, and it relies on burning charcoal placed on top of the tobacco to provide



**FIG. 1.** Schematic of a narghile water-pipe. The head, body, bowl, and hose are the primary "elements" from which a narghile is assembled. When a smoker inhales through the hose, a vacuum is created in the headspace of the water bowl sufficient to overcome the small (typically 3 cm of H<sub>2</sub>O) static head of the water above the inlet pipe, causing the smoke to bubble into the bowl. Simultaneously, air is drawn over and heated by the coal with some of it participating in the coal combustion, as evidenced by the visible red glow that appears during each puff. It then passes through the tobacco moisture, where due to hot air convection and thermal conduction from the coal, the mainstream smoke aerosol is produced. (Thermocouple is shown for experimental setup only.)



the heat needed to produce the aerosol, since unlike cigarette tobacco, the *ma'assel* is incapable of self-sustained combustion.<sup>(11)</sup> A field study in which smoking topography measurements were made for 52 narghile smokers in a café in Beirut<sup>(12)</sup> showed that narghile smoking sessions are of the order of 1 h in duration, during which hundreds of puff cycles are executed in a highly non-periodic fashion. For example, the median relative standard deviation for inter-puff interval for a single smoking session was 114%. Combined with the fact that “tar” production and tobacco temperature in narghile machine smoking are highly sensitive to inter-puff interval,<sup>(11)</sup> we concluded that the many puff cycles involved with narghile smoking could lead to significant cumulative errors when steady periodic machine smoking is used to estimate smoker exposure to various toxicants or to generate smoke aerosols for inhalation studies.

With this motivation, a digital smoking machine was developed for the narghile water-pipe in which the recorded smoking topography signal of a real smoker could be “played back” through the smoking machine, thus replicating in detail the smoker’s puffing behavior. This paper documents the design and testing of the “playback smoking machine,” and demonstrates its use in comparing a real recorded smoking session to its periodic analog in terms of carbon monoxide and total dry particulate matter yields (total particulate matter minus water), as well as the smoke aerosol temperatures attained in the narghile head. We were able to locate only one previous study in which an attempt was made to reenact a real smoking sequence using a smoking machine. In that study, Hinds et al.<sup>(13)</sup> used a manually controlled syringe smoking machine to produce sequential sinusoidal or square-wave puffs whose duration, volumes, and spacing matched those measured using smoking topography measurements of real smokers. The

goal of that study was to calculate respiratory deposition during smoking by comparing inhaled and exhaled particulate matter concentrations. The inhaled particulate matter was estimated by measuring particulate matter produced by machine smoking the cigarettes in the same sequence as measured using a puff topography device. The machine described here, in contrast, is fully automatic and follows the exact time varying flow signal produced by a smoker in its detail, without resort to assuming a particular puff waveform.

# Methods

## Smoking machine description

The smoking machine can be thought of as a device that communicates a vacuum signal to the smoking device (narghile) in a controlled manner. To play back a smoking session, the smoking machine controller must generate a timevarying control signal that yields the desired instantaneous flow rate (also known as “puff velocity” in the tobacco smoke research literature), which ranges from zero between puffs to the maximum flow attained during a given smoking session. As shown in Figure 2, this is accomplished by sending a varying DC voltage to a rapid response (20 msec closed to fully open) proportional control valve (Omega Engineering PV- 101) located between a continuously running vacuum pump and the narghile. When a command is issued to begin a puff, a three-way solenoid valve diverts the vacuum from the lab atmosphere to the smoking machine, and a flow is induced through the narghile. A 10-msec response time digital mass flow meter (Omega Engineering FMA-1609A), located upstream of the control valve, provides feedback to the controller.

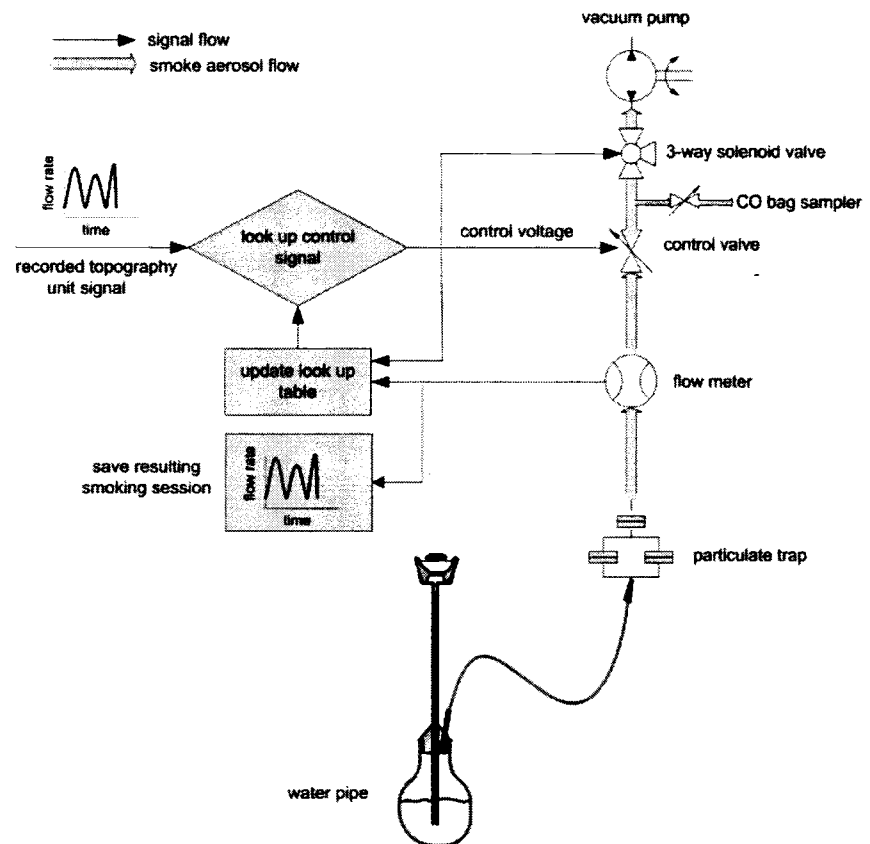


FIG. 2. Schematic of playback smoking machine.

This control valve signal is generated by a PCbased data acquisition and control (DAQ) system (National Instruments 6040E PCI card with SCB-68 signal conditioner) that is coded in the Labview® graphical programming language. During operation, the controller executes the following algorithm: (1) Read from the smoking session recording the desired flow rate during the next time interval (varying from 100 to 200 msec, depending on the resolution of the recording which is being played back). (2) Look up the control valve voltage expected to produce the desired flow rate. (3) Send that voltage to the proportional control valve. (4) Read the actual flow rate produced by that voltage. (5) Update the look-up table. (6) Read the next required flow rate, and so on until the end of the smoking session.

The look-up table is initialized prior to a playback session by a calibration program that increments the valve control voltage from zero to 10 V in 0.1-V steps while recording the resulting flow rates. Each initial entry of voltage in the table defines the center of a "neighborhood," whose width is 0.05 V. As the playback smoking session proceeds and new flow versus voltage data is acquired, the program searches the voltage domain for the appropriate neighborhood for each new data point. Having found the neighborhood, the program arithmetically averages the previous and current data pairs, and updates the table with this new average value. When looking up the control voltage for a flow rate that falls between two table entries, the program interpolates linearly between them.

Because the table is updated at the sampling frequency of the DAQ, changes in the flow resistance of the narghile or smoke sampling trap (which occur on the time scale of several puffs) as the smoking session proceeds are continuously accounted for and should not affect the accuracy of the playback session. One advantage of the adaptive look-up table approach is that no transfer function is needed

to relate control valve voltage and flow rate for the smoking machine and narghile; changes to the physical set-up, for example, by using a narghile of different flow geometry or a different type of particulate trap, does not require any new knowledge of the system's dynamic response to the control signal.

## Smoke sampling and analysis

As configured for this work, the smoking machine was equipped to capture the smoke particulate phase for dry particulate matter (DPM) determination, and to sample a fraction of the vapor phase for carbon monoxide (CO) determination. As shown in Figure 2, the smoke aerosol is split into two streams via a 30-degree Y-junction immediately downstream of the narghile hose outlet and each stream is drawn through a single 47-mm Gelman type A/E glass fiber filter pad. Each pad is held in a transparent polycarbonate holder, also manufactured by Gelman. This two parallel-filter configuration typically requires eight sets of filters (i.e., seven filter changes during each smoking session) to limit the particulate loading to circa 100 mg per filter. (ISO 4387:1991 specifies that up to 150 mg of tobacco smoke condensates may be collected on a 47-mm glass fiber filter pad.) A secondary filter is placed downstream of the second Y-junction and weighed before and after each smoking session to ensure that there is no breakthrough. The total particulate matter (TPM) was determined by weighing the filters before and after each smoking run. DPM was found by subtracting the mass of water on the filters from the TPM. To determine water mass, the 16 filter pads were combined in a 250- mL bottle and stirred for 20 min with 50 mL of ethanol. Five milliliters of the resulting solution was then added to the reaction chamber of a modified KF apparatus (Aquameyry II, Barnstead-Thermolyne). Using filter blanks with known quantities of water, we found that this extraction procedure was quantitative to the accuracy of the KF instrument.

For CO determination, a fraction of the smoke aerosol flow is sampled from the main flow path through a critical orifice by a miniature sealed diaphragm pump that exhausts into a 10-L tedlar grab sample bag (SKC, Inc., no. 232-08). The pump is activated during each puff by the DAQ system via a digital solid state relay. Carbon monoxide was quantified using a calibrated electrochemical CO analyzer (Monoxor II, Bacharach Inc.) that was connected to the grab sample bag after the smoking session was terminated. A limited number of experiments were made with a non-dispersive infrared CO analyzer (Emission Systems Inc., model no. 4001) to validate the measurement. Measured volume concentrations of CO were reported in units of mass by multiplying by the total drawn smoke volume and the density of the CO at ambient temperature and pressure. The initial dead volume between the sampling point and grab bag was negligible to the accuracy of the CO instrument, and was therefore excluded from analysis. Additional details regarding particulate and gas phase sampling set-up are given elsewhere.<sup>(14)</sup>

## Performance testing

Smoking machine performance was tested by comparing original and played-back recordings. The testing was conducted in two phases. Phase I was undertaken to test the ability of the controller and flow hardware to follow the records of the most challenging smoking behavior morphologies recorded in the aforementioned 52 smoker field study. The most challenging behavior for the smoking machine to reproduce is one where flow conditions change rapidly, for example when many short duration puffs are taken in rapid succession. Accordingly, seven smoking sessions (labeled A–G) were selected from the pool of 52 according to the criteria given in Table 1. Sessions A–G span the flow rates and puff volumes observed in the field study, and also correspond to the smoking sessions with the minimum puff durations, minimum interpuff

**TABLE 1.** Criteria used to select recorded smoking sessions for playback testing

Smoking parameter	Minimum	Maximum
Interpuff interval		
Mean	A	
Standard deviation		B
Puff duration		
Mean	C	
Standard deviation		D
Puff volume		
Mean	E	F
Standard deviation		D
Mean flow rate	E	G

Each letter represents a particular smoker that met the given category (e.g., smoker A had the minimum interpuff interval of the 52 smokers sampled, while smoker B had the maximum interpuff interval standard deviation).

intervals, and maximum variability in all smoking parameters (as indicated by standard deviation). Sessions A–G were recorded from three female and four male smokers who ranged from 21 to 33 years of age. The first 30 min of these recorded smoking sessions were re-played, with the narghile connected but not lit. The original and played-back smoking session flow signals were compared in terms of the session-averaged parameters given in Table 1.

In the second phase of testing, a single smoking session was chosen and played back in its entirety with the narghile in the lit condition. This was repeated five times. In the lit condition, the ability of the controller to adapt to the changing flow resistance as the filters are loaded with particulate matter and are replaced periodically during the playback session is tested. When a fresh filter replaces a loaded one, the smoking machine experiences a step decrease in flow resistance, and the controller must learn the new relationship between flow rate and control valve voltage. During the phase II testing, the original and played back smoking sessions were compared on a puff-by-puff basis as well as in terms of the total session-integrated parameters given in Table 1.

## Comparison of playback and periodic smoking aerosol components and temperatures

To illustrate potential use of the playback machine, DPM and CO yields, as well as smoke temperature and tobacco consumption were compared for a playback smoking session and its steady periodic analog. These diagnostics were chosen for their relative ease of measurement and because they broadly characterize differences which may arise in the composition of the gas and vapor phases of the aerosol as a result of the smoking regimen chosen. In particular, CO is primarily formed by the incomplete combustion of the charcoal, whose chemical kinetics are exponentially dependant on local temperature; differences in CO yields are therefore indicative of varying combustion chemistry arising from the varying puffing regimen, with potentially important effects on the yields of other pyrosynthesized compounds such as polycyclic aromatic hydrocarbons. DPM, on the other hand, is an aggregate representation of the aerosol particulate formation in the narghile head, resulting primarily from distillation of the tobacco mixture.<sup>(11)</sup> This distillation process is primarily controlled by the net thermal energy provided by the charcoal to the tobacco. Differences in DPM between playback and periodic smoking would thus indicate differences in the aggregate delivered energy, and the net transfer of material from the tobacco to the aerosol. This would be important for nicotine

and tobacco specific nitrosamines, both of which are delivered to the smoker by distillation from the tobacco.

The mean puff volume, duration, and interpuff interval were calculated (see Shihadeh et al, 2004 for equations) for a smoking session recorded from a 26-year-old male smoker, and these values were used to generate a steady periodic smoking regimen. The periodic regimen consisted of 182 puffs, each of 1020-mL volume and 3.9 sec duration, speed 15.3 sec apart. The playback and periodic smoking sessions were each replicated five times. Procedures for coal, tobacco, and narghile type, storage, and preparation, filter replacement schedule, and DPM and CO yield determinations were as presented elsewhere.<sup>(11,14)</sup>

To compare smoke aerosol temperatures resulting from playback and periodic smoking sessions, the head outlet temperatures measured using a K-type thermocouple (Fig. 1) were plotted against the cumulative drawn volume. To characterize overall differences in smoke aerosol temperature, the volume-weighted mean smoke temperature,  $\bar{T}$ , was calculated as

$$\bar{T} = \frac{\int \dot{Q}(t) T(t) dt}{\int \dot{Q}(t) dt}$$

where  $\dot{Q}(t)$  is the instantaneous volume flow rate and  $T(t)$  is the instantaneous temperature measured at the head outlet. The integrals were evaluated numerically using the trapezoidal rule.

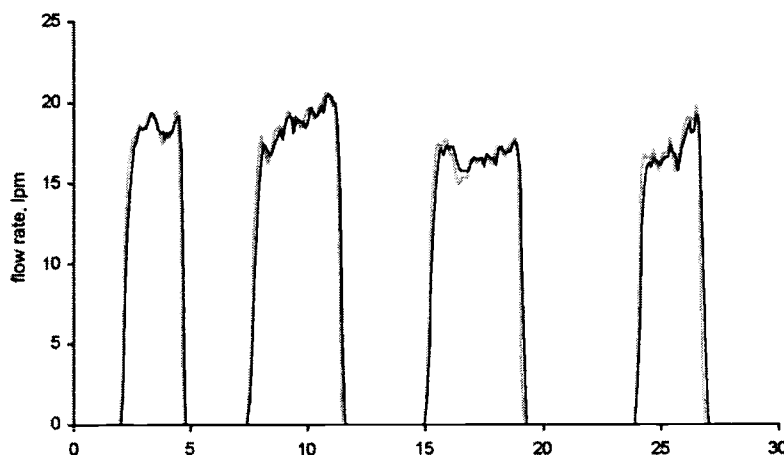


FIG. 3. Original and played-back flow rate traces for the first 30 sec of a 182-puff session. The original flow signal is shown in gray.

# Results and Discussion

## Phase I (unlit) smoking machine performance

Figure 3 shows recorded and played-back flow rate traces for the first 30 sec of a playback smoking session. It can be seen that the smoking machine reproduces the flow profiles in fine detail. Figure 4 shows the originally recorded and played-back session-averaged puffing parameters listed in Table 1 for the seven unlit selected smoking sessions. As shown, the session-average puff parameters were re-produced with an average error (deviation from a slope of unity) of less than 1%, indicating that the smoking machine is capable of following the range of smoking behaviors, including the most stochastic (large standard deviations) and dynamic (short puff durations and interpuff intervals), found in the 52-smoker pilot field study.

## Phase II (lit) performance

Figure 5 compares the field-recorded and machine- attained puff-resolved volume, duration, and interpuff interval for one of the five repeated smoking sessions with the narghile lit. The other four sessions provided essentially the same plots, and are not shown, though the slopes and coefficients of determination for the best linear regression relating the original and playback puffing parameters for the five sessions are given in Table 2. The slopes indicate the bias error, whereas the correlation coefficients indicate the precision at

**TABLE 2.** Slope and correlation coefficients for the relationship between recorded and played back puff-by puff volume, duration, and interpuff interval for five repeated tests with lit narghile

Test	Volume	Duration	Interpuff interval
1			
Slope	0.9922	1.0068	0.9996
R <sup>2</sup>	0.9976	0.9967	1
2			
Slope	1.0217	1.0115	0.9992
R <sup>2</sup>	0.9980	0.9972	1
3			
Slope	0.9839	1.0050	0.9997
R <sup>2</sup>	0.9923	0.9980	1
4			
Slope	1.0069	1.0138	0.9990
R <sup>2</sup>	0.9946	0.9970	1
5			
Slope	1.0301	1.0078	0.9995
R <sup>2</sup>	0.9972	0.9972	1

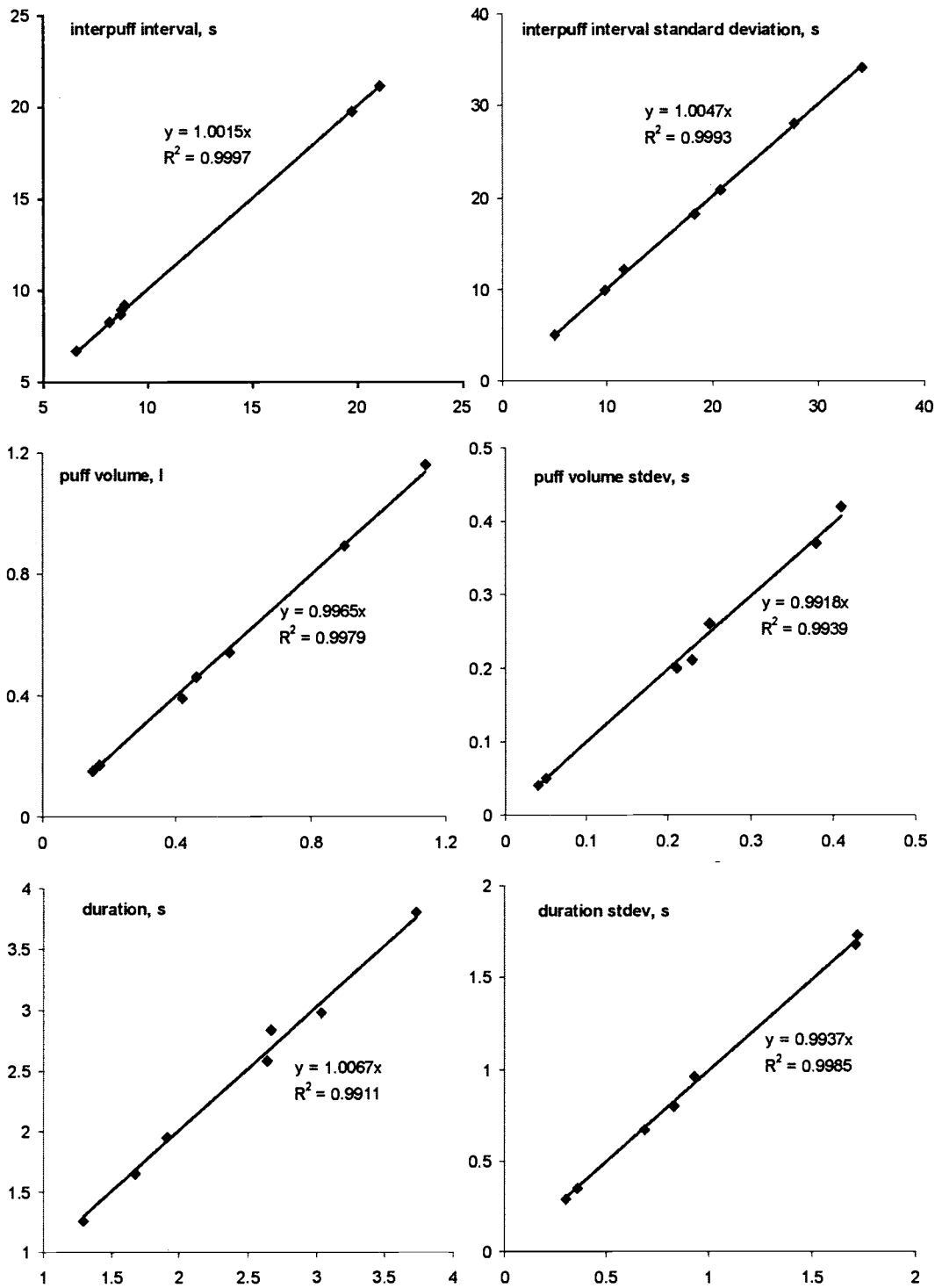
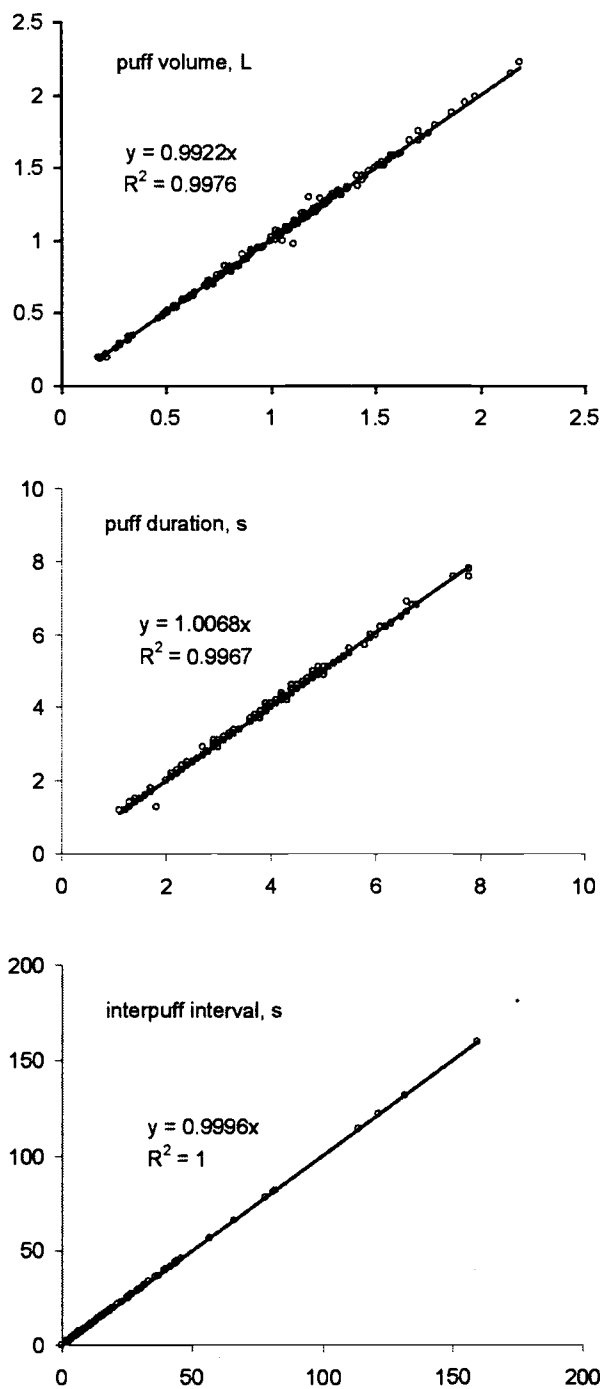


FIG. 4. Comparison of originally recorded and playback session-averaged puff parameters for smokers A–G. Horizontal and vertical axes correspond to original and playback data, respectively.



**FIG. 5.** Individual puff playback versus originally recorded volume, duration, and interpuff interval for lit smoking condition (test 1 in Table 3). Horizontal and vertical axes correspond to original and playback data, respectively.

the individual puff level. A low correlation coefficient, for example, would signify scatter about the mean. Variation from one test to another indicates smoking machine repeatability.

As shown in Table 2, the bias error is greatest for the puff volume, ranging from  $-2\%$  to  $3\%$  for the five smoking sessions. The puff volume is the most challenging parameter to reproduce because it is a product of the instantaneously varying flow rate and puff duration. The former depends on the accuracy of the look-up table and the response times of the control valve and flow meter as well as the inertia of the flow. The puff duration and interpuff intervals are accurate to less than  $1\%$  error, and the correlation coefficients for the three puff parameters are all better than  $99\%$ . As a whole, the data in Table 2 indicate that the playback machine is capable of reproducing with fidelity the detailed puff-by-puff behavior of a real smoker for the normal, lit condition during which the flow resistance is changing.

The session-average smoking parameters for the five tests above are given in Table 3 along with those of the original field-recorded session. Whereas the previous table indicated puff-by-puff performance, the data shown in Table 3 represents the integrated error over each entire smoking session. As shown, the average error for the five sessions is under  $1\%$  in any of the measured parameters, though the  $95\%$  confidence interval includes possible errors as large as  $4.43\%$  (mean error in puff volume standard deviation is  $0.98 \pm 3.45\%$ ).



**TABLE 3.** Comparison of recorded and played back session for integrated smoking parameters

Smoking parameter	Original recording	Repeated playback sessions					Error %	
		1	2	3	4	5	Mean	95% CI
Total drawn volume, L	185.6	183.9	189.9	182.5	187.2	191.0	0.70	± 2.46
Interpuff interval, sec								
Mean	15.32	15.29	15.27	15.30	15.26	15.29	- 0.25	± 0.13
Standard deviation	23.07	23.08	23.08	23.07	23.07	23.07	0.02	± 0.03
Puff duration, sec								
Mean	3.93	3.96	3.98	3.95	3.99	3.96	0.97	± 0.52
Standard deviation	1.34	1.34	1.34	1.34	1.34	1.35	0.15	± 0.41
Puff volume, L								
Mean	1.02	1.01	1.04	1.00	1.03	1.05	0.59	± 2.52
Standard deviation	0.41	0.41	0.42	0.41	0.40	0.43	0.98	± 3.45
Mean flow rate, L/min	15.25	14.96	15.37	14.88	15.07	15.52	- 0.59	± 2.23

The 95% confidence interval (CI) for the mean error is given in the last column, as calculated using the *t*-test distribution (*n* = 5).

### Tobacco consumed, DPM, CO, and smoke aerosol temperature for playback and periodic smoking

The mean and standard error of the mean (SEM) for tobacco consumed, DPM and CO yields, and smoke temperature for five replicate periodic and five replicate playback smoking sessions are provided in Table 4. The difference in mean CO between the playback and periodic sessions is significant at the 95% confidence level, and shows that the steady periodic smoking regimen results in a 20% under-estimate of the CO delivered to the smoker. The DPM yields, on the other hand were essentially the same for both types of smoking, and while the average tobacco consumed was almost 15% greater for playback smoking, the large relative SEM meant that the difference was not significant at the 90% confidence level.

The volume weighted mean smoke temperature exiting the narghile head was approximately the same for both types of smoking, though, as shown in Figure 6, the temperature fluctuates more for the playback smoking sessions, resulting in significantly higher peaks and lower minima. Since the hot combustion gases of the coal are measured after they have passed through the tobacco (and generated the smoke aerosol), the measured temperature fluctuations are actually damped by the thermal inertia of the moist tobacco paste. Temperature fluctuations in the combustion zone are expected to be considerably higher. We found that the data was very repeatable across periodic smoking sessions, while it varied considerably for the playback smoking sessions. The two playback temperature traces shown in Figure 6 are representative of the variations across repeated playback smoking sessions.

**TABLE 4.** Dry particulate matter, CO, tobacco consumed, and volume-weighted mean (SEM) smoke temperature for five repeated playback and five repeated periodic smoking sessions with the same number of puffs and mean puff parameters

	Playback	Periodic	Single cigarette <sup>15</sup>
DPM, mg	1004 (138)	1047 (140)	1-29
Co, mg	342 (21)	274 (13)	1-22
Tobacco consumed, g	7.0 (0.6)	6.0 (0.6)	—
Volume-weighted mean smoke temperature (°C)	110 (6.8)	103 (2.4)	—

CO, carbon monoxide; SEM, standard error of the mean; DPM, dry particulate matter; FTC, Federal Trade Commission.

## Conclusion

Steady periodic machine smoking protocols have long been used to estimate yields of various toxicants and to generate tobacco smoke aerosols for physical characterization and inhalation studies. This study has demonstrated a smoking machine and methodology for examining the implications of following a steady periodic versus actual smoking profile with the narghile waterpipe. It has been shown that the adaptive lookup table control approach provides good accuracy for playing back a wide range of puffing behavior morphologies, and is capable of tracking the desired flow signal even when the draw resistance in the smoking device or particulate sampling system is changing. For the smoking session examined, we found that the periodic smoking regimen results in a 20% under-prediction of the actual CO delivered to the smoker, while the DPM content and mean aerosol temperature were approximately the same. Further investigation is warranted to determine the generality of these results, as well as to compare other toxicologically significant measures such as polycyclic aromatic hydrocarbons (PAH), nicotine, and particle size distribution.

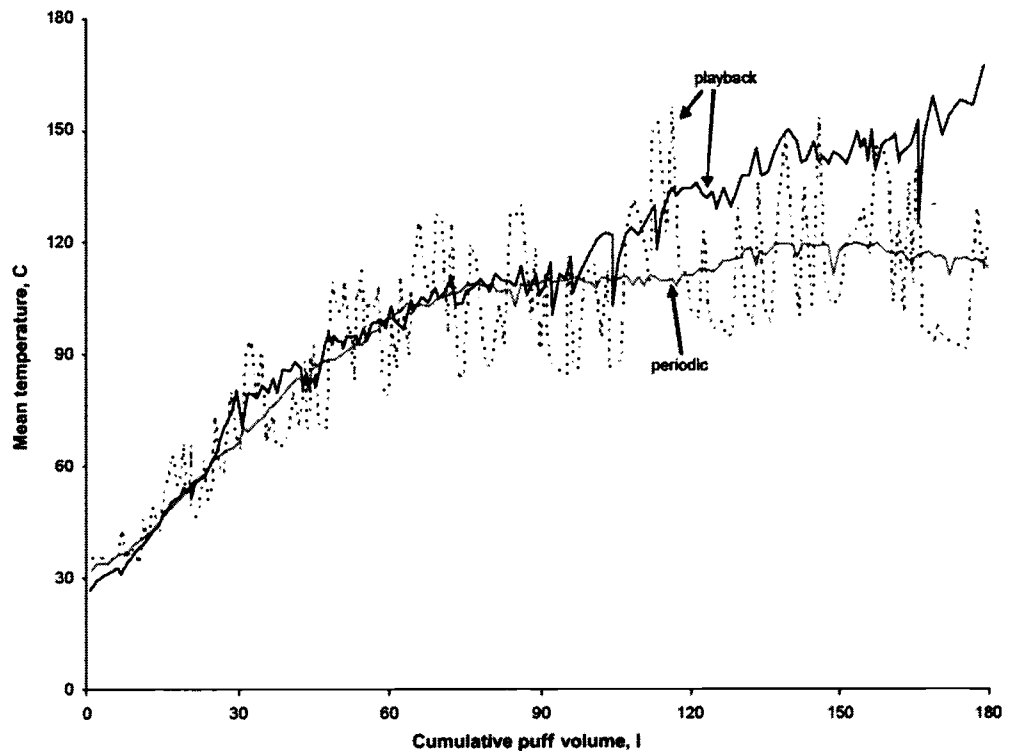


FIG. 6. Aerosol temperature ( $^{\circ}\text{C}$ ) at head outlet versus cumulative puff volume. Solid gray line shows typical data for periodic smoking sessions, whereas dashed and solid black lines show typical data for playback smoking.

It should be highlighted that, because the control algorithm requires no draw resistance model of the smoking device or sampling system, the playback machine is equally capable of generating smoke aerosols for cigarettes, pipes, and hand-rolled marijuana cigarettes in a playback mode using prior smoking topography recordings. The only modification needed for these relatively low-flow smoking devices would be the replacement of the flow meter used in this study with one of a lower flow range. We would expect slightly higher smoking machine accuracy with these smoking devices, because they are not accompanied by pressure perturbations generated by a water bubbler, and because the smaller stored volume and flow path length in the devices (relative to the waterpipe) will reduce

characteristic response times between the vacuum applied at the mouthpiece and the resulting smoke flow rate. Given the greater role of tobacco combustion (rather than distillation as with the narghile) to the formation of the mainstream aerosol, we speculate that differences in chemical composition between playback and periodic smoking may be even more important than with the narghile. Apart from playback smoking, the use of a continuously running vacuum pump modulated by a digitally controlled flow valve, rather than the conventional use of a piston-cylinder device to generate a Gaussian puff profile, affords the specification of any smoking waveform desired, and generally at lower cost.

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**A PORTABLE, LOW-RESISTANCE PUFF  
TOPOGRAPHY INSTRUMENT FOR PULSATING,  
HIGH-FLOW SMOKING DEVICES**

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## Abstract

A smoking topography instrument appropriate for pulsating high flow rate smoking devices, such as the narghile water pipe, has been developed and tested. Instrument precision and repeatability was determined using a digitally controlled smoking machine, and the added draw resistance due to the topography instrument was measured over the range of expected puff flow rates. The maximum error in any topography variable was found to be less than 5%. The instrument was successfully demonstrated in a pilot field study of 30 volunteer narghile smokers. The pilot study yielded an average smoker puff volume, duration, and interpuff interval of 0.53 l, 2.47 sec, 16.28 sec, respectively.

## Introduction

This work has its roots in study of the toxicology of the *narghile* water pipe, a tobacco-smoking device indigenous to Southwest Asia, whose use has reached beyond its traditional physical and social borders to include young women and men across the Arabic-speaking world and beyond. Recent smoking machine studies (Shihadeh, 2003) at the AUB Aerosol Research Lab showed that the quantities of “tar” and nicotine delivered to the narghile smoker are strongly dependent on the puffing parameters used, even when the total volume drawn is held constant. It was found, therefore, that toxicological assessment of narghile smoking requires accurate models of smoking behavior on the basis of studies of smokers. For similar and other reasons, smoking topography instruments (STIs) for cigarettes have been previously developed and deployed to study cigarette smoking (Guyatt & Baldry, 1988; Guyatt, Kirkham, Mariner, Baldry, & Cumming, 1989;

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Puustinen, Olkkonen, Kolonen, & Tuomisto, 1987), but these are inappropriate for the pulsating high-flow rates that characterize water pipe smoking. This report documents the development of an STI that can be used with the narghile and other pulsating high-flow smoking devices in field studies of smokers in their natural settings.

Conventional cigarette-smoking topography instruments utilize an obstruction-type differential pressure flow sensor incorporated into a cigarette holder that is attached to the filter end of the cigarette. As the smoker draws a puff, a pressure differential is generated in the mouthpiece, and the pressure signal is converted to a voltage that is digitized and recorded for subsequent statistical analysis. Common topography measures include puff volume, puff duration, and interpuff interval.

Figure 1 illustrates the main features of the narghile water pipe. When a smoker inhales through the hose, a vacuum is created in the water bowl sufficient to overcome the small static head above the inlet pipe, causing the tobacco smoke to bubble into the bowl. During each puff, air is drawn over and heated by the coals, some of it participating in coal combustion. Several large holes in the base of the clay head allow the smoke to pass into the central conduit of the body, that leads to the water bowl. The characteristic flow passage diameter throughout the narghile is approximately 1 cm. Unlike the cigarette, there is no well-defined point at which the narghile has been consumed; in general, the smoker simply stops when the smoke is no longer appealing, whether due to a change in flavor as the tobacco is consumed, to a sense of satiation, or to a change in social setting.

From a fluid mechanics perspective, cigarette puffing differs qualitatively from narghile puffing in that the former possesses a relatively low volume and high resistance character. For cigarette topography, this factor facilitates the

design of a pressure differential meter, because the large existing flow resistance masks any additional flow resistance imposed by a flow sensor. In the case of the water pipe, puffing is akin to a free inhalation, meaning that the smoker can tolerate less of an artificially imposed flow resistance. This compounds the difficulty of obtaining a high signal-to-noise ratio in flow measurement, since the pressure perturbations caused by bubbling can be of the order of magnitude of the pressure differential available for flow measurement.

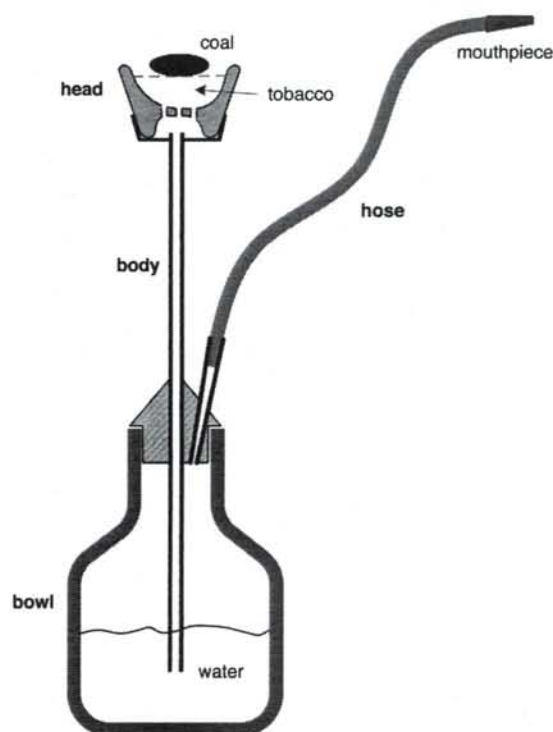


FIGURE 1. Narghile water pipe schematic.

## Method

### Device Description

A detailed design and experimental study was undertaken to balance the opposing requirements of a high-flow, low draw resistance sensor and a high signal-to-noise ratio. Early experiments with hot wire type mass flow sensors (Honeywell AWM series) showed excellent signal response, insensitivity to pressure pulsations, and low flow resistance, but these were unable to withstand more than two smoking sessions before the sensor failed, due to the buildup of smoke particulate matter. As an alternative, the traditional pressure differential obstruction meter was pursued, using pulsation dampers to remove the fluctuating components of the signal. The final design utilizes a polycarbonate medical research differential pressure flow sensor (Novamatrix Medical neonatal sensor) in a 50% bypass flow configuration. This bypass ratio provides a workable tradeoff between a higher signal-to-noise ratio and added flow resistance. The pressure ports of the flow sensor are connected by  $\frac{1}{8}$ -in. flexible Tygon tubing to a pair of 1,280-cc glass pulsation-damping bottles, which in turn are connected to an analog differential pressure transducer. The signal output of the pressure transducer feeds to a 22-bit analog-to-digital

data logger, and the logged data can be periodically downloaded through a serial port to a PC. A rechargeable battery and voltage regulators provide the power for the data logger and for pressure transducer excitation. The entire setup fits in a small tool box and weighs approximately 2 kg. Miscellaneous flow fittings were fabricated from polypropylene. This design was found to be robust, with no required replacement of any of the components for the duration of the pilot study.

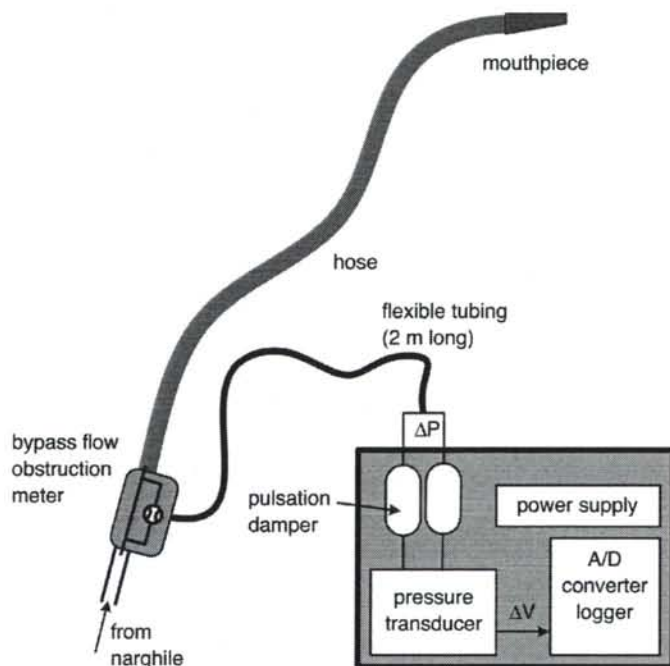


FIGURE 2. Prototype topography unit (not to scale).

As is shown in Figure 2, the sensor is incorporated into a typical narghile hose at its point of connection with the water pipe, far from the mouthpiece. A typical hose is approximately 1 m in length. As such, attachment of the sensor does not impose any modification in smoking method. Unlike the cigarette holder utilizing topography systems now in use, the taste and feel—both in the



fingers and on the lips—of the smoking device remain unchanged. It has been found that cigarette holders can influence smoking behavior, due to varied sensory effects (Hoefler, Nil, & Baettig, 1991).

Because the flow sensor is attached to the hose, field data collection requires replacement of the smoker's original hose with the topography unit hose at the beginning of the smoking session. The setup time is under 1 min, making it convenient for field studies of randomly approached smokers.

The logged data, consisting of transducer voltage versus elapsed time, is processed using a Matlab-based code that reads the pressure transducer signal and locates the timings corresponding to

the beginning and end of each puff. Puff events are defined by deviation of the pressure transducer signal from the zero flow voltage, plus a threshold setting to eliminate noise from registering as a puff. In this case, the threshold was set equal to the data logger accuracy of 0.039 v, which corresponds to a sensor flow rate of 1.6 lpm. Other user input tolerances include a minimum time separation between two puffs to ensure that a stray zero voltage is not read as the end of a puff when it occurs in the midst of one. Negative voltages, which occasionally occur at the end of a puff due to transducer bounce, are reassigned to zero. The software includes a graphical user interface (Figure 3) to facilitate use by field workers.

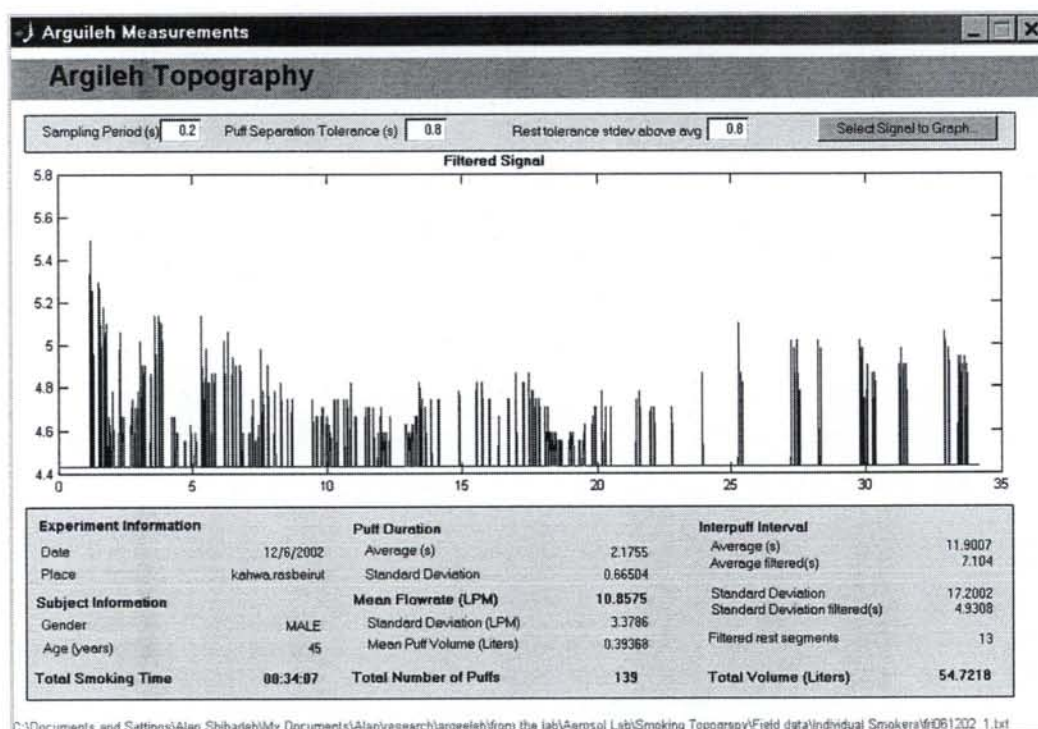


FIGURE 3. Smoking topography instrument graphical user interface. Sample data are shown, with each puff appearing as a vertical line whose height is proportional to flow rate. Smoking session statistics are indicated.

Having determined the beginning and end timings of a given puff, the software calculates the instantaneous puff flow rate  $\dot{q}(t)$ , using an experimentally derived input calibration curve of transducer voltage versus flow rate. Figure 4 shows the highly correlated ( $R^2 > .99$ ) flow versus pressure data fitted to a second-order polynomial equation. The volume of each puff  $i$  is defined as the integral of the volumetric flow rate with respect to time:

$$v_i = \int_{t_{\text{sop}(i)}}^{t_{\text{eop}(i)}} \dot{q}_i(t) dt,$$

where  $t_{\text{sop}(i)}$  and  $t_{\text{eop}(i)}$  are the times at the start and the end of a puff  $i$ , respectively. The integral is evaluated numerically from the recorded data, using the trapezoidal rule, and the mean flow rate for puff  $i$  is then calculated as

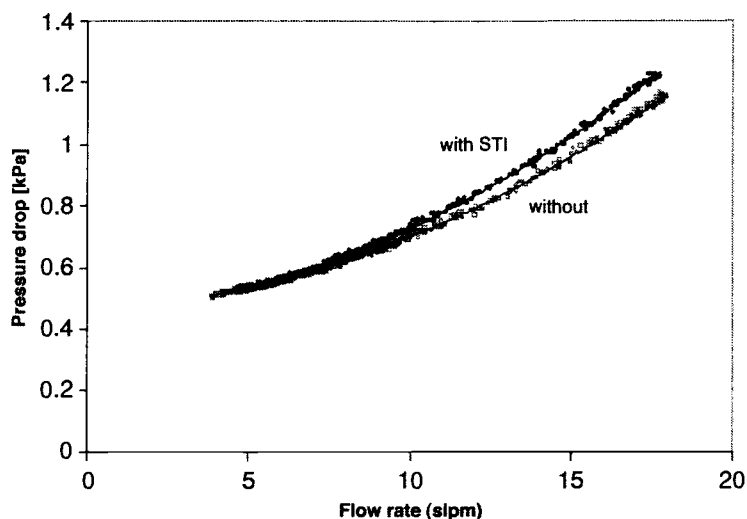
$$\bar{q}_i = \frac{v_i}{t_{\text{eop}(i)} - t_{\text{sop}(i)}}.$$

The data from the puff events are stored in an array from which the total number of puffs and the mean puff volume, duration, and interpuff interval are calculated for a given smoking session.

### Instrument Performance Testing

The STI was laboratory tested to determine the additional flow resistance imposed by it on the smoker, as well as its accuracy in terms of several smoking topography parameters: total number of puffs, average puff volume and duration, and average interpuff interval. In addition to the laboratory testing, the unit was field tested for its ease of use and acceptance by volunteers.

The laboratory tests were carried out using a previously described smoking machine (Shihadeh, 2003), which was upgraded by the incorporation of digital control of the puffing regimen (previously controlled by a solenoid



**FIGURE 4.** Draw pressure versus flow rate for standard narghile with and without the flow sensor attached.

valve and timer) and by the use of a calibrated analog output electronic mass flow meter (Omega Engineering Model FMA-1608) and data acquisition system. This allowed simultaneous acquisition and subsequent comparison of the STI signal and the smoking machine flow rate. A single smoking machine puffing regimen was made using a constrained random number generator to determine the duration of each puff and rest interval for 100 consecutive puff cycles. Each puff was randomly assigned a duration ranging from 1.5 to 4 sec, followed by a rest time, which could range from 5 to 30 sec, in accordance with the values found in the pilot field study. Using this numerically generated puffing regimen, 11 tests were made in which the only variant was the flow rate; it was varied from a nominal 6–18 slpm (standard liters per minute), to correspond to the range observed in the pilot study.

The snap action of the smoking machine solenoid valve gave a nearly instantaneous zero-to-full flow rate (and vice versa) puffing regimen and provided a difficult test of STI responsiveness and ability to follow the smoker. Transient response is an issue because the pulsation-damping bottles used to smooth the pressure perturbations act in an analogous manner to an RC filter, introducing a system response time constant proportional to their volume. If the bottles are too large, they will introduce an excessive lag, causing an overestimation of the puff duration; if they are too small, the damping effect will be insufficient to reduce the ratio of fluctuating to mean pressure, and accuracy will be sacrificed.

To determine the additional draw resistance imposed by the STI, a static pressure tap and transducer were fitted to the mouthpiece of the hose, which in turn was attached to a standard size narghile that had been prepared for smoking in accordance with the procedures specified in

Shihadeh (2003). The pressure transducer and mass flow meter signals were acquired by a PC as the flow rate was varied from 5 to 20 slpm. The test was conducted with and without the STI installed, in order to determine the added draw resistance.

The pilot field study was conducted at a café near the American University of Beirut, where the narghile is commonly served. When a café customer ordered a narghile, the food server notified the field worker, who then proceeded to recruit the customer as a volunteer in the study. If informed consent was obtained, the STI was attached to the narghile upon its delivery by the food server. The STI was then left with the smoker for approximately 40 min of unsupervised smoking in the café. Because it was physically unobtrusive (placed under the table, out of sight), it was expected that the recorded smoking sessions would closely resemble the “natural” smoking behavior of the smokers in this common setting. A total of 30 smokers were sampled in this fashion. In addition to age and gender, volunteers were asked whether they sensed any differences in smoking or had any complaints in connection with the use of the STI.

## Results

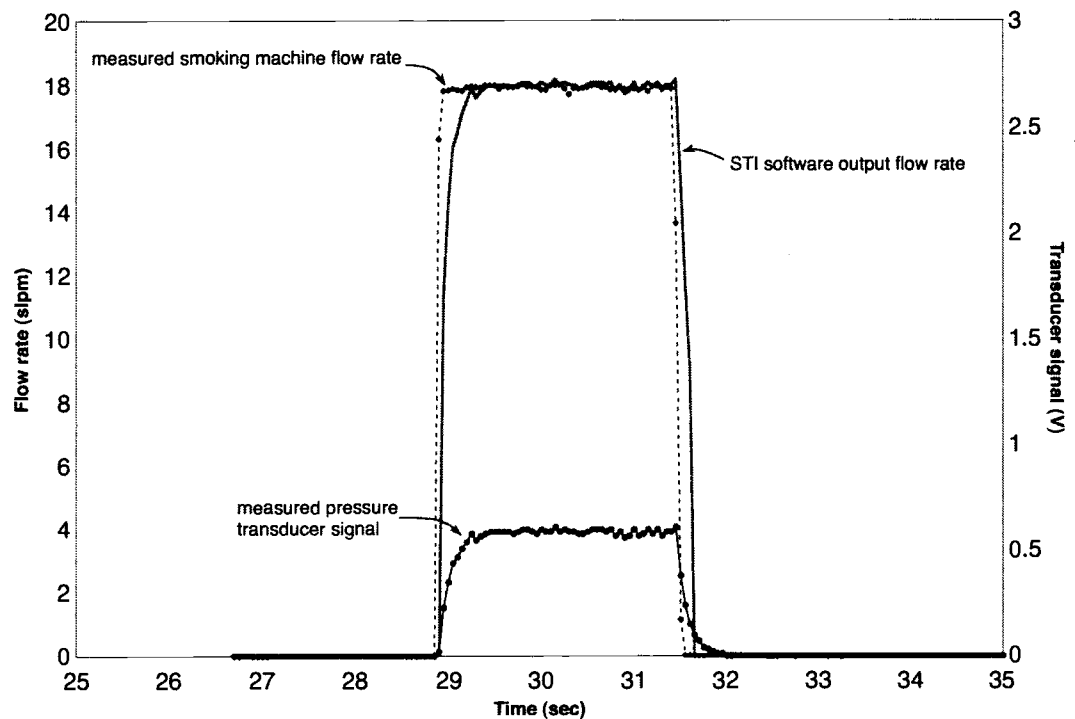
### Flow Resistance

As is shown in Figure 4, the pressure drop through the narghile with the STI installed was only slightly greater than the base case, with an additional draw pressure of 0.04 kPa (a 5% increase) at the average 13-slpm fieldmeasured flow rate. At the highest flow rate of 20 slpm, the added draw resistance was 0.1 kPa (an 8% increase).

The measurement confirmed that the draw resistance through the narghile is far less than that through a cigarette. Tip-ventilated cigarettes at a standard testing flow rate of 1.05 lpm demonstrated pressure drops of approximately 1.2 kPa (Guyatt et al., 1989); at this pressure drop, the narghile provides more than 17 times the flow rate of the cigarette.

### Dynamics and Accuracy

Figure 5 shows the smoking machine flow rate, the STI pressure transducer signal, and STI output versus time for a single sample puff recorded in the laboratory, using the smoking machine. As is shown, the pressure transducer signal exhibits a lagging step response characteristic of first-order systems and



**FIGURE 5.** Smoking machine, smoking topography instrument (STI), and pressure transducer output signals for a single puff.

has a characteristic time constant of approximately 100 msec. This is an expected effect of the pulsation dampers, which introduce a large capacitance in the pressure domain. This response lag, in turn, leads to overestimating the puff duration (particularly the time corresponding to the end of puff) and underestimating the flow rate in the early portion of the puff, as can be seen by comparing the “smoking machine” and “software output flow rate” curves. Fortunately, the two effects tend to cancel when the puff volume is calculated.

Also noticeable in Figure 5 is the relatively large signal-to-noise ratio of the transducer, providing reasonable accuracy in calculating the instantaneous flow rate from the flow calibration equation. Without the dampers, the pulsating and mean pressure signals were found to be indistinguishable.

Table 1 shows the tabulated results of the random machine-smoking sessions at varying

flow rates. The STI showed a maximum absolute error of 4.5% in puff volume and duration. The puff volumes, durations, and interpuff intervals of the repeated Tests 4–10 yielded a coefficient of variation of less than 1%.

### Pilot Field Study

More than 85% of the approached candidate volunteer smokers were willing to have the STI attached to their narghile and participate in the study. On two occasions, volunteer smokers complained of a strong residual flavor in the pipe from a previous smoking session and aborted the test shortly after starting. It was noted that the previous smoking sessions had used a rose-flavored tobacco, which apparently produces a discordant aroma when followed by the more common fruit flavors (apple, cherry, and strawberry). According to the café food servers, this is a common complaint, which is normally resolved by replacing the narghile

**TABLE 1** Comparison of Smoking Machine and Smoking Topography Instrument (STI) Determined Smoking Parameters for 13 Smoking Sessions

Trial	Puff Volume (l)			Puff Durations (sec)			Interpuff Interval (sec)		
	Machine	STI	% Error	Machine	STI	% Error	Machine	STI	% Error
0	0.23	0.23	0.0	2.50	2.52	0.8	19.10	19.09	-0.5
1	0.39	0.40	2.6	2.48	2.59	4.4	19.13	19.02	-0.6
2	0.41	0.42	2.4	2.53	2.49	-1.6	17.65	17.69	0.2
3	0.54	0.55	1.9	3.45	3.37	-2.3	17.70	17.80	0.6
4	0.55	0.54	-1.8	2.51	2.55	1.6	19.09	19.06	-0.2
5	0.55	0.55	0.0	2.53	2.55	0.8	19.08	19.06	-0.1
6	0.55	0.55	0.0	2.52	2.56	1.6	19.09	19.06	-0.2
7	0.55	0.55	0.0	2.51	2.55	1.6	19.10	19.06	-0.2
8	0.56	0.55	-1.8	2.54	2.55	0.4	19.07	19.06	-0.1
9	0.55	0.54	-1.8	2.53	2.54	0.4	19.08	19.06	-0.1
10	0.56	0.55	-1.8	2.54	2.55	0.4	19.07	19.06	-0.1
11	0.67	0.64	-4.5	2.55	2.53	-0.8	19.06	19.09	0.2
12	0.77	0.75	-2.6	2.61	2.51	-3.8	19.01	19.09	0.4

Note — Trials 4–10 were performed to test STI repeatability. The same stochastic puffing routine was utilized for all the trials except Trials 2 and 3.

hose. The data from these sessions were not tabulated. Other than these instances, no volunteer smoker noted any sensory difference from normal narghile smoking, and none aborted the test. After each day of data collection, during which, typically, four smoking sessions were recorded, the STI was left connected to a compressed air line overnight, to reduce buildup of the aromatic smoke particulates from day to day.

The results from the pilot study are given in Table 2. Although the mean puff duration of 2.47 sec is comparable to the 1- to 2.4-sec range previously reported for cigarette smokers (U.S. Department of Health and Human Services, 1988), the mean puff flow rate of 12.9 lpm (215 ml/sec) is more than one order of magnitude greater than the FTC method's 17.5 ml/sec, resulting in a mean puff volume 16 times larger. The mean interpuff interval of 16.4 sec falls just under the previously reported range of 18–64 sec for cigarette

smokers (U.S. Department of Health and Human Services, 1988). The large interpuff interval standard deviation is indicative of the sporadic nature of the smoking ritual. Inspection of the session recorded in Figure 3, for example, reveals long rest periods punctuated by closely spaced puffing events.

It is interesting to note that at the mean smoker peak flow rate of 20.9 lpm, the expected narghile draw pressure is 1.3–1.4 kPa on the basis of extrapolation from the data given in Figure 4, approximately the same as that measured in previous cigarette puff topography experiments. This could indicate some intrinsic limit, across smoking delivery methods, in the maximum smoker draw pressure.

**TABLE 2** Pilot Study Results

Parameter	Mean	Minimum	Maximum	SD
Smoking time (min:sec)	39:20	29:54	53:33	5:21
Number of puffs	137.1	44	226	51.7
Smoker mean puff duration (sec)	2.47	1.22	4.52	0.77
Smoker mean puff volume (l)	0.53	0.15	1.11	0.22
Smoker mean puff flow rate (lpm)	12.90	5.57	16.16	2.58
Smoker peak flow rate (lpm)	20.31	10.47	28.98	4.28
Smoker mean interpuff interval (sec)	16.28	7.06	34.11	8.28
Smoker interpuff interval SD (sec)	23.49	6.95	70.83	15.53

Note —  $N = 30$  smokers, each sampled for approximately 40 min of unsupervised smoking in a local café. Smoking time and number of puffs reflect those measured during the 40-min trial; most smokers continued smoking after the smoking topography instrument was removed. All the participants were smoking in the mo'assel narghile configuration (see Shihadeh, 2003, for narghile typologies).

## *Discussion*

A portable smoking topography unit appropriate for high flow rate water pipe smoking has been demonstrated in laboratory and field testing. The additional draw resistance of 0.1 kPa at the peak flow rate of 20 lpm imposed by the STI on the smoker is within the range of draw resistances resulting from normal variations in water pipe design and preparation that are routinely tolerated by smokers. For example, water height in a given narghile can vary by 2 cm from one smoking session to another, causing a change in draw resistance of 0.2 kPa. Other factors, such as the degree to which the tobacco is packed in the head, the geometry of the flow passages, and the method of application of coals to the head, are also expected to provide variations in draw resistance from one smoking session to another.

The instrument demonstrated a degree of precision and overall accuracy acceptable for use in field studies of water pipe smokers and demonstrated a reasonable tradeoff between responsiveness and accuracy. The maximum recorded error was 4.5% for any smoking parameter. Some improvement in detecting the end of a puff (and therefore, in the puff volume and duration calculations) may be realized by sensing the end of the puff by the slope of the pressure transducer signal, rather than by its magnitude.

The pilot study showed a high acceptance rate among approached candidate volunteers, indicating that the device was not overly cumbersome as configured and packaged. The smokers indicated that they sensed no difference when smoking through the STI. The tabulated results from the field study showed that narghile smoking involves much higher flow rates and puff volumes than cigarette smoking does and differs to a lesser degree in interpuff interval and puff duration.

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**TobReg Advisory Note:**

**WATERPIPE TOBACCO SMOKING:  
HEALTH EFFECTS, RESEARCH NEEDS AND  
RECOMMENDED ACTIONS BY REGULATORS**

WHO Study Group  
on Tobacco Product  
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The World Health Organization (WHO) was established in 1948 as a specialized agency of the United Nations serving as the directing and coordinating authority for international health matters and public health. One of WHO's constitutional functions is to provide objective and reliable information and advice in the field of human health, a responsibility that it fulfils in part through its extensive programme of publications.

The Organization seeks through its publications to support national health strategies and address the most pressing public health concerns of populations around the world. To respond to the needs of Member States at all levels of development, WHO publishes practical manuals, handbooks and training material for specific categories of health workers; internationally applicable guidelines and standards; reviews and analyses of health policies, programmes and research; and state-of-the-art consensus reports that offer technical advice and recommendations for decision-makers. These books are closely tied to the Organization's priority activities, encompassing disease prevention and control, the development of equitable health systems based on primary health care, and health promotion for individuals and communities. Progress towards better health for all also demands the global dissemination and exchange of information that draws on the knowledge and experience of all WHO's Member countries and the collaboration of world leaders in public health and the biomedical sciences.

To ensure the widest possible availability of authoritative information and guidance on health matters, WHO secures the broad international distribution of its publications and encourages their translation and adaptation. By helping to promote and protect health and prevent and control disease throughout the world, WHO's books contribute to achieving the Organization's principal objective -- the attainment by all people of the highest possible level of health. In pursuit of this end, the Organization has vested the Director-General with the mandate to establish study groups to tackle scientific issues where WHO is expected to formulate policies to assist governments in formulating national regulations that have public health significance. The following advisory note is the result of the deliberations of one of the study groups so created, the WHO Study Group on Tobacco Product Regulation.

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## Preface

Tobacco product regulation, which includes regulating the contents and emissions of tobacco products via testing, mandating the disclosure of the test results, and regulating the packaging and labelling of tobacco products, is one of the key pillars of any comprehensive tobacco control programme. The Contracting Parties to the World Health Organization Framework Convention on Tobacco Control (WHO FCTC), a binding international treaty, are bound, *inter alia*, by the Treaty's provisions concerning tobacco product regulation contained in its Articles 9, 10 and 11.

The sound scientific information provided by a WHO scientific advisory group on tobacco product regulation, established in 2000 specifically to fill the knowledge gaps that existed at the time in the area of tobacco product regulation, served as the basis for the negotiations and the subsequent consensus reached on the language of these three articles of the Convention.

In November 2003, in recognition of the critical importance of regulating tobacco products, the WHO Director-General formalized the ad hoc Scientific Advisory Committee on Tobacco Product Regulation (SACTob) by changing its status to that of a study group. Following the status change, the SACTob became the "WHO Study Group on Tobacco Product Regulation" (TobReg). It is composed of national and international scientific experts on product regulation, tobacco-dependence treatment, and the laboratory analysis of tobacco ingredients and emissions. Its work is based on cutting-edge research on tobacco product issues. It conducts research and proposes testing in order to fill regulatory gaps in tobacco control. As a formalized entity of WHO, TobReg reports to the WHO Executive Board through the Director-General in order to draw the Member States' attention to the Organization's efforts in tobacco product regulation.

This advisory note on Waterpipe tobacco smoking: health effects, research needs and recommended actions by regulators has been prepared by the WHO Study Group on Tobacco Product Regulation, in accordance with the prioritized work programme of the WHO Tobacco Free Initiative and with the provisions of the WHO FCTC concerning tobacco product regulation, in response to requests made by those Member States whose populations are exposed to this form of tobacco use. The Study Group approved and adopted the present advisory at its second meeting held in Rio de Janeiro, Brazil on 7 to 9 June 2005.

The Study Group's members serve without remuneration in their personal capacities rather than as representatives of governments or other bodies; their views do not necessarily reflect the decisions or the stated policy of WHO. The members' names are provided in the annex to this document.

## **Acknowledgements**

The WHO Tobacco Free Initiative and the WHO Study Group on Tobacco Product Regulation wish to acknowledge the significant contributions made by Dr Alan Shihadeh (Lebanon) and Dr Thomas Eissenberg (United States of America). In early 2005, Drs Shihadeh and Eissenberg were commissioned by TFI to write a background paper on waterpipe tobacco smoking, including its prevalence, chemistry and toxicology, pharmacological effects and health hazards. As part of their effort to achieve in-depth research on the issues, Drs Shihadeh and Eissenberg collaborated with Dr Wasim Maziak of the Syrian Center for Tobacco Studies and investigators from the Egypt Smoking Prevention Research Initiative, namely Drs Ebenezer Israel (United States), Christopher Loffredo (United States) and Mostafa K. Mohamed (Egypt).

The results of the work commissioned by the WHO Tobacco Free Initiative served as the basis for discussion on the issue during the Second meeting of the WHO Study Group on Tobacco Product Regulation, held in Rio de Janeiro, Brazil in June 2005. This scientific advisory note is a direct product of the deliberations that took place at that meeting.

The WHO Tobacco Free Initiative and the WHO Study Group on Tobacco Product Regulation also wish to acknowledge the contributions made by Sara Hughes in the referencing and Ellen Joy Adriano and Dawn Mautner in the formatting and design preparation of the final document.

# WHO Study Group on Tobacco Product Regulation

## Advisory Note:

### Waterpipe Tobacco Smoking: Health Effects, Research Needs and Recommended Actions by Regulators

#### Purpose of advisory

This advisory note, formulated by the WHO Study Group on Tobacco Product Regulation (TobReg), addresses the growing concerns about the increasing prevalence and potential health effects of tobacco smoking using waterpipes, also called “waterpipe tobacco smoking”. The purposes of the advisory are to provide guidance to WHO and its Member States, to inform regulatory agencies in their efforts to implement the provisions of the WHO Framework Convention on Tobacco Control concerning education and communications, and to educate consumers about the risks of waterpipe smoking. The advisory also provides guidance to researchers and research agencies interested in facilitating a more thorough understanding of the health effects of tobacco waterpipe smoking, and to those engaged in developing tobacco smoking prevention and cessation programmes so that such programmes accommodate the unique aspects of waterpipe smoking.

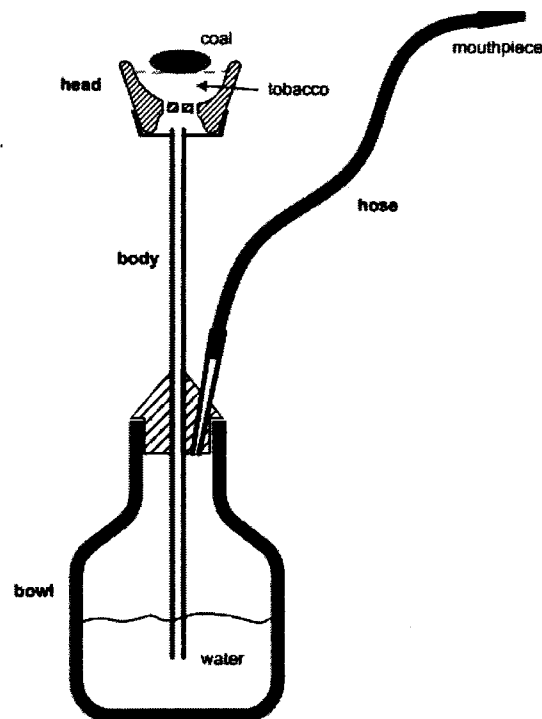
#### Background and history

Waterpipes have been used to smoke tobacco and other substances by the indigenous peoples of Africa and Asia for at least four centuries (1). According to one historical account (1), a waterpipe was invented in India by a physician during the reign of Emperor Akbar (who ruled from 1556 to 1605) as a purportedly less harmful method of tobacco use. The physician Hakim Abul Fath suggested that tobacco “smoke should be first passed through a small receptacle of water so that it would be rendered harmless” (2). Thus, a widespread but unsubstantiated belief held by many waterpipe users today – that the practice is relatively safe – is as old as the waterpipe itself (3). Marketing tools associated with waterpipes and waterpipe tobacco may reinforce this unsubstantiated belief (4). For example, the label of a popular waterpipe tobacco brand sold in South-West Asia and North America states “0.5% nicotine and 0% tar”.



## Description of waterpipes and waterpipe smoking

Generally, waterpipes have a head, body, water bowl, and hose (see figure). Holes in the bottom of the head allow smoke to pass into the body's central conduit. This conduit is submerged in the water that half-fills the water bowl. The hose is not submerged, exits from the water bowl's top, and ends with a mouthpiece, from which the smoker inhales. The tobacco that is placed into the head is very moist (and often sweetened and flavoured): it does not burn in a self-sustaining manner. Thus, charcoal is placed atop the tobacco-filled head (often separated from the tobacco by perforated aluminium foil) (4, 5). When the head is loaded and the charcoal lit, a smoker inhales through the hose, creating a vacuum above the water, and drawing air through the body and over the tobacco and charcoal. Having passed over the charcoal, the heated air, which now also contains charcoal combustion products, passes through the tobacco, and the mainstream smoke aerosol is produced (6). The smoke passes through the waterpipe body, bubbles through the water in the bowl, and is carried through the hose to the smoker (7). During a smoking session, smokers typically replenish and adjust the charcoal periodically. A pile of lit charcoal may be kept in a nearby firebox for this purpose. As an alternative, smokers may opt for commercially available quick-lighting charcoal briquettes.



There are regional and/or cultural differences in some waterpipe design features, such as head or water bowl size, number of mouthpieces, etc., but all

waterpipes contain water through which smoke passes prior to reaching the smoker. Names for the waterpipe also differ, and include “narghile” in East Mediterranean countries including Turkey and Syria, “shisha” and “goza” in Egypt and some North African countries, and “hookah” in India (8).

Waterpipes can be purchased from dedicated supply shops, including Internet vendors, which also sell charcoal, tobacco and accessories. Waterpipes are now being marketed as portable, with the introduction of accessories such as carrying cases with shoulder straps. Some accessories are sold with claims to reduce the harmfulness of the smoke, such as mouthpieces that contain activated charcoal or cotton, chemical additives for the water bowl, and plastic mesh fittings to create smaller bubbles. None of these accessories have been demonstrated to reduce smokers’ exposure to toxins or risk of tobacco-caused disease and death.

### **Health effects**

Contrary to ancient lore and popular belief, the smoke that emerges from a waterpipe contains numerous toxicants known to cause lung cancer, heart disease, and other diseases (4). Waterpipe tobacco smoking delivers the addictive drug nicotine, and, as is the case with other tobacco products, more frequent use is associated with the smokers being more likely to report that they are addicted (9).

A waterpipe smoking session may expose the smoker to more smoke over a longer period of time than occurs when smoking a cigarette. Cigarette smokers typically take 8–12, 40–75 ml puffs over about 5–7 minutes and inhale 0.5 to 0.6 litres of smoke (10). In contrast, waterpipe smoking sessions typically last 20–80 minutes, during which the smoker may take 50–200 puffs which range from about 0.15 to 1 litre each (6). The waterpipe smoker may therefore inhale as much smoke during one session as a cigarette smoker would inhale consuming 100 or more cigarettes.

While the water does absorb some of the nicotine, waterpipe smokers can be exposed to a sufficient dose of this drug to cause addiction (8, 11). Nicotine intake is an important regulator of tobacco intake in general, as evidenced by the fact that cigarette smokers tend to smoke until they get enough nicotine to satisfy their need and addiction, but not so much as to cause nausea (12, 13). It is likely that the reduced concentration of nicotine in the waterpipe smoke may result in smokers inhaling higher amounts of smoke and thus exposing

themselves to higher levels of cancer-causing chemicals and hazardous gases such as carbon monoxide than if none of the nicotine was absorbed by the water; however, this issue needs further study (4, 14, 15). This puts waterpipe smokers and second-hand smokers at risk for the same kinds of diseases as are caused by cigarette smoking, including cancer, heart disease, respiratory disease, and adverse effects during pregnancy (16).

### **Regional and global patterns of waterpipe smoking**

Waterpipe smoking is often social, and two or more people may share the same waterpipe (3, 6). In South-West Asia and North Africa, it is not uncommon for children to smoke with their parents (17). If used in a commercial establishment such as a café or restaurant, the waterpipe is ordered (often from a menu of flavours) and an employee prepares it from an in-house stock (8).

Globally, the highest rates of smoking occur in the African Region (primarily North Africa), the Eastern Mediterranean Region and the South-East Asia Region (6). Since the 1990s waterpipe smoking appears to be spreading among new populations such as college students and young persons in the United States, Brazil and European countries. Waterpipe smoking appears to be stimulated by unfounded assumptions of relative safety compared to cigarettes, as well as the social nature of the activity (18). Commercial marketing, often with implicit or explicit safety-related claims, may also be contributing to the spread of waterpipe smoking across the globe. Waterpipe smokers may use waterpipes exclusively; however, many smokers may also smoke cigarettes. In some countries in which cigarette smoking is concentrated among men, waterpipe smoking appears more evenly distributed between both sexes (8, 19). All these findings reinforce the need to conduct more research on waterpipes and the issues surrounding their use, and then to disseminate the information on the health risks to all countries.

### **Science base and conclusions**

Waterpipe smoking has not been studied as intensively as has cigarette smoking; however, preliminary research on patterns of smoking, the chemistry of the smoke that is inhaled, and health effects supports the idea that waterpipe smoking is associated with many of the same risks as cigarette smoking, and may, in fact, involve some unique health risks. The science base supports the following conclusions:

1. Using a waterpipe to smoke tobacco poses a serious potential health hazard to smokers and others exposed to the smoke emitted (9).
2. Using a waterpipe to smoke tobacco is not a safe alternative to cigarette smoking (4).
3. A typical 1-hour long waterpipe smoking session involves inhaling 100–200 times the volume of smoke inhaled with a single cigarette (6).
4. Even after it has been passed through water, the smoke produced by a waterpipe contains high levels of toxic compounds, including carbon monoxide, heavy metals and cancer-causing chemicals (8, 14).
5. Commonly used heat sources that are applied to burn the tobacco, such as wood cinders or charcoal, are likely to increase the health risks because when such fuels are combusted they produce their own toxicants, including high levels of carbon monoxide, metals and cancer-causing chemicals (7, 15).
6. Pregnant women and the fetus are particularly vulnerable when exposed either actively or involuntarily to the waterpipe smoke toxicants (16).
7. Second-hand smoke from waterpipes is a mixture of tobacco smoke in addition to smoke from the fuel and therefore poses a serious risk for non-smokers (8).
8. There is no proof that any device or accessory can make waterpipe smoking safer.
9. Sharing a waterpipe mouthpiece poses a serious risk of transmission of communicable diseases, including tuberculosis and hepatitis (4).
10. Waterpipe tobacco is often sweetened and flavoured, making it very appealing; the sweet smell and taste of the smoke may explain why some people, particularly young people who otherwise would not use tobacco, begin to use waterpipes (20).

## **Research needs**

There is surprisingly little research addressing tobacco smoking using a waterpipe, especially given that there are many millions of current waterpipe smokers and that waterpipe use is spreading across the globe. A more thorough understanding of waterpipe smoking, risks, and health effects requires worldwide efforts to study:

1. Types and patterns of smoking across regions and cultures.
2. National and global trends in waterpipe smoking.
3. How the chemical and physical properties of the smoke depend on the waterpipe set-up and smoking conditions (geometry of waterpipe, amount/type of coal and tobacco used, puffing behaviour, etc.).
4. Methods for evaluating toxicant yield, smoker exposure, and resultant absorption.
5. Patterns of smoking by individuals and how different smoking patterns relate to the smokers' intake of smoke toxicants, including nicotine, carcinogens, carbon monoxide, and other disease-causing compounds.
6. Relationships among yield, exposure, and absorption biomarkers.
7. Pharmacology and toxicology of smoke as assessed in laboratory tests using biological assays and in actual use by people.
8. Epidemiology of waterpipe-associated disease risk, including addiction and transmission of non-tobacco, communicable diseases.
9. The influence of cultural and social practices on initiation and maintenance.
10. The relationship between waterpipe smoking and other forms of tobacco, including substitution and multiple product smoking.
11. The relationship between waterpipe smoking and the use of other drugs, including marijuana.
12. Development of prevention and cessation strategies.

## **Suggested actions for regulators (consistent with the definition of “tobacco product” under the WHO Framework Convention on Tobacco Control)<sup>1</sup>**

The WHO’s Study Group on Tobacco Product Regulation (TobReg) urges consideration of the following public health initiatives to reduce waterpipe smoking and associated disease.

1. Waterpipes and waterpipe tobacco should be subjected to the same regulation as cigarettes and other tobacco products.
2. Waterpipes and waterpipe tobacco should include strong health warnings.
3. Claims of harm reduction and safety should be prohibited.
4. Misleading labelling, such as “contains 0 mg tar”, which may imply safety should be prohibited.
5. Waterpipes should be included in comprehensive tobacco control efforts, including prevention strategies and cessation interventions.
6. Waterpipes should be prohibited in public places consistent with bans on cigarette and other forms of tobacco smoking.
7. Education of health professionals, regulators and the public at large is urgently needed about the risks of waterpipe smoking, including high potential levels of second-hand exposure among children, pregnant women, and others.
8. The TobReg recommends that a full document be produced in the WHO Technical Report Series to evaluate thoroughly the health effects of waterpipes and to develop recommendations.

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<sup>1</sup> Article 1.f states that “tobacco products” mean products entirely or partly made of the leaf tobacco as raw materials which are manufactured to be used for smoking, sucking, chewing and snuffing.

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