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Review of human smoking behaviour and recommendations for a new ISO standard for the machine smoking of cigarettes

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TECHNICAL REPORT

ISO/TR 17219

First edition
2013-09-15

Review of human smoking behaviour and recommendations for a new ISO standard for the machine smoking of cigarettes

Évaluation des données relatives au comportement du fumeur et recommandations relatives à une nouvelle norme ISO concernant le fumage mécanique de cigarettes

Reference number
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Contents

Page

Foreword ..... **v**

0 Introduction ..... **vi**

1 Scope **1**

2 Abbreviated terms **1**

3 Smoking machine regimes **2**
3.1 Abstract 2
3.2 General 2
3.3 Why have a smoking regime? 2
3.4 What was the original reason for testing cigarettes and how were parameters selected? 3
3.5 What are smoking regimes currently used for? 7
3.6 Smoking machine capabilities 8
3.7 A look into the future 10
3.8 Smoking regimes (historical) 10

4 Summary of literature data on smoking topography **11**
4.1 Abstract 11
4.2 Introduction and methods 11
4.3 Results 12
4.4 Discussion and conclusions 15

5 A brief review of the incidence, degree and consequences of filter ventilation hole blocking **29**
5.1 Abstract 29
5.2 Filter ventilation — Basic information 29
5.3 The degree of vent hole blocking and its effect on yields obtained during human smoking 33
5.4 The effect of vent blocking on puffing topography 36
5.5 The effect of vent blocking on puffing topography — Conclusion 40

6 A review of cigarette butt lengths typically achieved by smokers when smoking their usual brand **40**
6.1 Abstract 40
6.2 Introduction 41
6.3 Analytical smoking 41
6.4 Current international standard for analytical smoking 44
6.5 Conditions of consumer use 44
6.6 Comparison of butt lengths observed under conditions of use with machine-based smoking standard butt lengths 46
6.7 Recommendation for an appropriate butt length specification more representative of smokers' behaviour 48

7 Cigarette smoking and nicotine intake **53**
7.1 General 53
7.2 Introduction 53
7.3 Nicotine metabolism 54
7.4 Nicotine intake and switching studies 54
7.5 Nicotine yield in machine smoking methods other than FTC [e.g. Massachusetts Department of Public Health (MDPH) more intense machine-smoking parameters] 56
7.6 Nicotine yield in machine smoking methods other than FTC- Health Canada (HC) parameters 56
7.7 Summary and conclusions 56

8 Recommendations **57**
8.1 Option A 58
8.2 Option B 59
8.3 Option C 59

Documents
Document Sharing Hub

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Full document details: PD ISO/TR 17219:2013

8.4 Variability and reproducibility of data 59
8.5 Gaps in knowledge 59

Bibliography **61**

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Foreword

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ISO/TR 17219 was prepared by Technical Committee ISO/TC 126, *Tobacco and tobacco products*.

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0 Introduction

0.1 Editorial comments

This Technical Report is based on the report of the ad hoc Smoking Behaviour Review Team to ISO/TC 126. To meet ISO Central Secretariat requirements for Technical Reports the following editorial changes have been necessary.

— The Executive Summary has been made into a Conclusion.

— 'Scope' and 'Abbreviated terms' clauses have been added.

— The Bibliographies that appeared at the end of each chapter in the original report have been combined at the end of the Technical Report. Some footnotes have been replaced by notes in the text or by reference to the Bibliography.

— ISO Technical Reports are a work product of an ISO Technical Committee and as such do not have named authors.

— In the Introduction some repetition has been removed (two paragraphs describing the preparation of the report have been combined) and one paragraph was moved as a consequence.

0.2 Background

Smoking machines for measuring cigarette smoke yields were initially developed in the 1930s. The 35 ml puff volume currently used in both the International Organization for Standardization (ISO) and US Federal Trade Commission (FTC) methods was originally proposed by Bradford in 1936. Throughout the 1950s and early part of the 1960s various smoking machines were developed each using a set of parameters to define how the cigarette was smoked. Examination of the data showed that smoke yields were dependent on the smoking parameters used in the methodologies.

In 1966 the FTC in the US proposed a standardised machine smoking method with a smoking regime of 35 ml puff volume, 2 s puff duration and one puff per min. The rationale for adopting a standardised smoking regime was outlined in an FTC press release issued in 1967. The FTC stated that the method enabled products to be ranked in terms of their tar and nicotine yields. They also claimed that the yields obtained using their method would not provide individuals or groups of smokers with the precise amounts of tar or nicotine they would obtain from cigarettes. This limitation of the FTC method arises because smokers exhibit a wide range of smoking behaviour characteristics while the smoking machine uses a fixed standardised smoking regime.

Other national standards institutes had developed machine smoking methods in parallel to the activities in the US. Most of these adopted the 35 ml puff volume, 2 s duration and 1 puff per min regime, but there were differences between the various methods in factors such as butt lengths, type of smoking machine used, and the method of collecting smoke.

By the end of the 1980s a number of standardised machine smoking methods were in use worldwide. These included FTC, ISO and CORESTA methods, and methods used by the standards authorities in the UK, Germany, Canada, Australia, New Zealand and Japan. In 1988 ISO recommended that a standard worldwide smoking method was needed and they asked CORESTA to conduct the experimental work necessary to produce and validate a revised standard method. A comprehensive series of studies were subsequently conducted by CORESTA and a revised ISO method was introduced in 1991.

The ISO standard method is now used worldwide with the exception of the US and Japan. However, both the FTC method in the US and the Japanese standard method are very similar to the ISO method.

Periodically, the parameters used in the standardised machine smoking methods have been criticized for not being representative of the behaviour parameters produced by smokers. Critics have raised the following points.

— Many human smoking behaviour studies show that many smokers take larger and more frequent puffs than the standardised smoking machine.

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— As a result of their more intensive puffing behaviour smokers may obtain higher smoke yields than those reported using standard methods.

— Some smokers have been observed to alter their smoking behaviour when switching to a lower yield cigarette e.g. increasing puff volume. This phenomenon is frequently referred to as "compensation". All cigarettes are tested using the same parameters under the ISO/FTC method. Consequently, declared ISO/FTC yields would provide misleading information to smokers on the ranking of brands by smoke yields if they compensate to such an extent that rank order of yields is no longer maintained.

— The filter ventilation zones are unblocked when cigarettes are smoked using the ISO and FTC methods. However smokers may block some of the ventilation holes with their fingers or lips when smoking. Ventilation hole blocking may result in increases in smoke yields.

The WHO formed a group called the "WHO Study Group on Tobacco Product Regulation" (TobReg). During the first meeting of the TobReg group in October 2004 there was a discussion between TobReg members and representatives of ISO including the Secretariat of ISO/TC 126. TobReg expressed its view that "*the current ISO standard for machine measurement of cigarette emissions is not a valid means of comparing different brands of cigarettes relative to their emissions, human exposures that result from their use, or for purposes of regulation*". TobReg requested that ISO modify the ISO machine standard for measuring cigarette emissions.

Representatives from the WHO Tobacco Free Initiative and TobReg were invited to present their views on the ISO method at the annual meeting of ISO/TC 126 in Geneva in 2004. It was decided that the following actions should be taken:

1) To consider an amendment to the scope of ISO 4387.

2) To review worldwide human smoking behaviour, uptake studies, and smoking methods in order to advise ISO/TC 126.

3) Based on the review outline in 2) to consider the development of a robust and practical smoking regime that as far as possible is representative of smokers' behaviour and that has acceptable reproducibility and variability.

4) To report back to ISO/TC 126 with any proposals for a new work item.

0.3 Mandates

ISO/TC 126 proposed the formation and approved the membership of the present ad hoc group and prepared a detailed statement of work for that group. The purpose of the work was defined as:

— Identify one or more sets of values for smoking machine parameters for additional method(s).

— Propose machine smoking methods(s) more relevant to smoking behaviour which could reflect maximum yields.

— The existing ISO methods should be retained and evaluated as giving lower yields.

The ad hoc Smoking Behaviour Review Team was established with the following terms of reference.

1) To review worldwide human smoking behaviour documentation, uptake studies and smoking methods to advise ISO/TC 126.

2) To report maximum and minimum values for puff volume, puff duration, puff frequency, ventilation blocking, butt lengths and other parameters.

3) To recommend one or more sets of parameters for potential new practical machine smoking regimes in addition to the existing ISO standard (ISO 3308).

4) To identify gaps in existing knowledge.

0.4 Ad hoc Smoking Behaviour Review Team, ISO/TC 126

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This report is the joint effort of the Smoking Behaviour Review Team members. The report begins with an Executive Summary outlining the recommendations of the ad hoc group. The Executive Summary was authored collectively by the ad hoc group. Each member of the ad hoc group prepared a chapter that addresses the issues named in the mandate.

The Executive Summary includes:

— a history and overview of machine smoking protocols;

— a review and summary of the published literature and some recent unpublished data on smoking topography, including a summary of puff volumes, puff durations, puff frequencies and puff numbers grouped according to ISO/FTC tar yields, geographical location and date of data collection;

— literature on filter ventilation and ventilation hole blocking;

— a review of the literature and a clause on butt length;

— an overview of studies that address the issue of cigarette smoking and nicotine intake and uptake.

0.5 Limitations

In the following clauses each of the main parameters of machine smoking are discussed. It is acknowledged that there are limitations to the use and the interpretation of smoking machine yields. Most important among the limitations of the machine smoking methods is the recognition that no machine standard can truly reflect the wide range of human smoking behaviour. People smoke cigarettes differently. The variability between smokers can be due to pharmacological as well as social, economic, and cultural differences. Furthermore smoking topography in the same person varies as a function of the time of day, social circumstance, time since the last cigarette, and the number of cigarettes smoked among other possible influences. Finally, puffing parameters differ over the course of a single cigarette. For example smokers may take larger and more frequent puffs at the beginning of a cigarette and smaller and less frequent puffs toward the end of the cigarette. It is also possible that blocking of filter ventilation holes differs over the course of smoking a single cigarette. Specifically, vent blocking may occur when some puffs are taken but not others. Thus the provisions of machine standards where all puffs are identical through the entire cigarette rod, the intervals between puffs are identical, the vent blocking is constant and the inter-puff interval is constant, does not reflect the large diversity in smoking behaviour.

In spite of these limitations the use of machine smoking represents a tenable solution to the complex problem of assigning and studying yields of commercially available cigarettes. The results of such tests are useful for the assessment of the delivery of components of tobacco smoke and for comparisons of cigarettes on the delivery of nicotine, tar, carbon monoxide and other components of tobacco smoke. The consideration of new parameters for the machine smoking regimen is appropriate because of changes in cigarettes and the consumption patterns of smokers.

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Review of human smoking behaviour and recommendations for a new ISO standard for the machine smoking of cigarettes

1 Scope

This Technical Report was prepared by an ad hoc Smoking Behaviour Review Team to address the following terms of reference:

a) to review worldwide human smoking behaviour documentation, uptake studies and smoking methods;

b) to report maximum and minimum values for puff volume, puff duration, puff frequency, ventilation blocking, butt lengths and other parameters;

c) to recommend one or more sets of parameters for potential new practical machine smoking regimes in addition to the existing ISO standard (ISO 3308);

d) to identify gaps in existing knowledge.

2 Abbreviated terms

Avg	Average
CORESTA	Centre de Coopération pour les Recherches Scientifiques Relative au Tabac
DoH	Department of Health (formerly known as DHSS)
DHSS	Department of Health and Social Security
FTC	Federal Trade Commission
Ind.	Individual
RH	Relative Humidity
Run	The smoking run that the cigarette was smoked in
Tar	Nicotine Free Dry Particulate Matter (NFDPM)
Tipping	Overwrap - i.e. the wrapping material applied to the mouth end of the cigarette
TNCO	Tar, nicotine and carbon monoxide
TSNAs	Tobacco specific nitrosamines
UKAS	United Kingdom Accreditation Service
USPO	United States Patent Office
Yield	The concentration of analyte measured in the smoke (normally per cigarette) when smoked in a prescribed manner

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cig^{-1}	per cigarette
CV(%)	Coefficient of variation (relative standard deviation)

3 Smoking machine regimes

3.1 Abstract

The way that a human smokes a cigarette is extremely variable. Two smokers picked at random will probably not smoke the same brand of cigarettes in the same manner. A single individual will smoke two cigarettes of the same brand differently depending on a whole range of factors, e.g. on the time of day. Even during the time it takes to smoke one cigarette a single smoker may change his behaviour during the smoking process on that same cigarette, e.g. reducing puff volume towards the end of smoking the cigarette. Therefore it is not possible to develop a smoking regime which is capable of mimicking human smoking behaviour. The best that can be achieved is to design a smoking regime with a fixed set of parameters to achieve reproducible results that is loosely based on human smoking behaviour. The diversity of smoking behaviour allows plenty of scope for the development of a wide range of smoking regimes that can claim to be representative. An additional complication is that smoke yields of tar, nicotine and carbon monoxide have decreased for many brands over the last few decades and this has arguably had a significant effect on human smoking behaviour.

This Technical Report looks at current smoking regimes, why they are used, what are the important parameters that need to be controlled and how good are the regimes at determining reproducible smoke yields for tar, nicotine and carbon monoxide. In particular this Technical Report looks at:

— the purpose of a smoking regime;

— the development of the four major smoking regimes that are used today: ISO, FTC, Canadian Intense and Massachusetts;

— parameters that need to be controlled as part of a smoking regime;

— smoking machines — what are their limitations and how practicable would it be to develop a new smoking regime;

— the use of smoking regimes for products other than cigarettes and in the determination of analyte yields other than tar, nicotine and carbon monoxide.

3.2 General

This report looks at why (a) smoking regimes are used, (b) a history of how smoking machine regimes have developed since testing of cigarettes began, (c) current smoking machine regimes and (d) current smoking machine capabilities.

3.3 Why have a smoking regime?

Testing of cigarettes began many decades ago. "…some of the first workers to attempt to define a standard puff volume were Pyfl and Schmidt[3] in 1933. From measurements made on seven different smokers, they recorded a mean puff volume of 40 cm^3 (ml) of 2 s (second), taken twice a minute"[4].

It would have soon become apparent that smoking machine parameters needed to be controlled if reproducible results for smoke yields were to be obtained. The current list of primary parameters that are controlled include:

— puff volume;

— puff duration;

— puff frequency;

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— butt length (at which smoking should cease).

In addition other factors should be controlled to obtain reproducible results within and between laboratories when using the same analytical method. They include:

— conditioning of cigarettes;

— environmental conditions in which the smoking is performed;

— air flow across the cigarette;

— insertion depth of the cigarette into the holder;

— puff profile — this is a measure of puff flow rate — being a combination of puff volume and puff duration;

— type of trap;

— representative sample;

— vent blocking (yes/no).

3.4 What was the original reason for testing cigarettes and how were parameters selected?

One of the original reasons for testing cigarettes was to compare smoke yields from different cigarette brands. It was obvious from the beginning that:

a) smokers can smoke different brands of cigarettes in different ways;

b) a smoker smokes the same brand of cigarettes differently during the day. For example, one study found that "… smoking in situations that caused physical stress (e.g. when waiting) resulting in a shortening of puff interval (35 s instead of 43 s)"[5];

c) a smoker often changes the way the cigarette is smoked during the smoking process, the most common observation being that puff volume and duration decreases as the cigarette is smoked whereas puff interval increases. This might be due to satiation of the nicotine craving and an increase in "smoke concentration" as the cigarette is smoked by the consumer. However, Buzzi "concluded that the sensory consequences of the physicochemical changes in smoke composition between the first and last puff or other as yet unknown psychological factors are more likely candidates than nicotine satiation for explaining the typical changes in puffing behaviour along burning time of a cigarette."[6]

Therefore, it was apparent that the parameters selected to operate a smoking machine would have to be a composite as it was not practicable to replicate human smoking behaviour.

3.4.1 Development of the ISO smoking regime

Joseph Johnson gives a good summary of how some of the early parameters for the ISO smoking regime were arrived at.

"In 1961, observations were made on 312 UK smokers by Research Services Ltd on behalf of the Tobacco Manufacturers Standing Committee. The average values from one cigarette type were found to 14 puffs, 12 min bare time, a frequency of 1,17 puffs per min and a butt length of 18 mm. When the same cigarette type was smoked on a machine it was found that a 25 cm^3 (ml) puff volume of 2 s duration taken once per minute gave an alight time of 12 min and a butt length of 18 mm.[7] These parameters were considered to be realistic and were adopted as the UK standard. During the same time period some other countries had standardised on the 35 cm^3 puff although a 40 cm^3 puff was used in the Federal Republic of Germany and Romania.[8]

In 1969, on the initiative of the German Institute for Standardization (DIN), a Technical Committee on Tobacco and Tobacco Products was formed.[9] One of the first actions of this group was to recommend the 35 cm^3 puff volume of 2 s duration taken once a minute as standard — largely because most of the

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participating laboratories had a substantial amount of data based on this regime"[4]. As a result of this recommendation the puff volume in the UK standard method was changed to 35 ml in 1970.

3.4.2 Development of the FTC smoking regime

The original methods for measuring tar and nicotine yields in cigarette smoke came from a variety of sources: "In 1936, the American Tobacco Company began using standard machine smoking conditions, which, to some extent, reflected the smoking habits of cigarette smokers at that time. The estimated sales-weighted average nicotine yields of the cigarettes smoked at that time were around 2,8 mg"[10]. By the early 1960s, different manufactures were using varying methodologies to obtain tar and nicotine smoke yields which meant that the results were not very comparable. Something needed to be done to sort the situation out.

The FTC prohibited manufacturers making claims about tar and nicotine yields that could not be substantiated by competent scientific proof. However as evidence grew about the potential harmful effects of smoking cigarettes, it was felt that consumers should be provided with information about tar and nicotine yields. This would enable them to choose a brand with e.g. a lower tar yield. Therefore, there was a requirement to establish a standardised testing protocol for assessing tar and nicotine smoke yields.

One of the earliest collaborative studies of a smoking method took place in 1964 and was based on work carried out by laboratories from the tobacco industry. Dr Ogg who worked for the US Department of Agriculture acted as the convenor. Cigarettes were conditioned for 24 h at 75 °F (23,9 °C) and 60 % Relative Humidity and 5 cigarettes were smoked per channel with a puff volume of 35 ml, a puff duration of 2 s and a puff frequency of 60 s.[11] TPM yields ranged from around 35 mg cig^{-1} down to 20 mg cig^{-1} and nicotine yields from 1,8 mg cig^{-1} down to 1,1 mg cig^{-1}. In 1967, the FTC cigarette laboratory began operations based on Dr Ogg's work and the methodology adopted was to take one puff of two seconds' duration and 35 ml puff volume every minute. It was reported (Chapter 2 — Monograph 7 — FTC cigarette test method[12] that Harold Pillsbury had asked Dr Ogg how he had come up with the specific parameters of the collaborative trial protocol. He replied that they had been based on personal observations and since there was no such thing as an average smoker, he had selected parameters that seemed reasonable in light of his observations.

"In 1980 the protocol was broadened to include measurement of the carbon monoxide yields as well"[12].

3.4.3 Development of the Canadian Intense smoking regime

It was of concern to many that the ISO smoking regime produces yields on the low side of what a "typical" smoker could be reasonably expected to inhale. Work had been carried out by Labstat Inc. for the Federal Government of Canada to look at the effect of different smoking parameters on analyte yield. In one study: "Three levels of each of five smoking parameters: butt length, puff duration, puff interval, puff volume, and ventilation occlusion were examined, and the effects on puff number and total particulate matter (TPM) as well as gas phase, particulate phase, and total HCN yields were estimated"[13]. Based on these investigations, the legislators in the Canadian province of British Columbia proposed that a smoking regime be introduced with a 56 ml puff volume and a puff frequency of 26 s.[14] In addition ventilation holes on the filter would be fully blocked. It was felt that this regime would produce yields that would be more representative of maximum intake by the smoker. At a later date, the parameters were modified to 55 ml puff volume and 30 s puff frequency and adopted at the Federal level in Canada.

3.4.4 Development of the Massachusetts smoking regime

In 1996, the director of the Massachusetts tobacco control program proposed regulations which would require tobacco companies to report accurate nicotine ratings for cigarettes. Additional testing of cigarettes was to be performed when determining nicotine yields using different puff volumes and frequency and requiring some form of vent blocking. This was part of a strategy to provide meaningful cigarette labelling.

The original intention was to choose two sets of smoking machine parameters that better represent (a) what an "average smoker" might inhale and (b) maximal yields that a "heavy smoker" might produce.

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The "average smoker" regime may have been based on a proposed specification change to the FTC protocol. The proposed regulations were revised before coming into force in 1997 and the "heavy smoking regime" was dropped.

3.4.5 Deciding on a suitable butt length

Many surveys of butt lengths have taken place and the measurement of butt lengths can be done precisely so that an accurate mean can be produced. However, smokers are less obliging in their smoking and a wide range of values have been found. In one study, a mean butt length of 22,1 mm was found for filter cigarettes (1959) in West Germany but 10 years later another study found the length to be 30,6 mm for the same country. The authors found that "There are significant differences in butt length for different sections of the population, e.g. sex, place, occupation, geographic location, and economic conditions, brand, etc."[5]. Not surprisingly early smoking regimes often used different butt lengths. Harmonization of standards has reduced the number of alternatives and improved precision of smoke yields obtained by a smoking machine. However, it might be argued that this is at the expense of flexibility to reflect what happens with smoking behaviour in different parts of the world.

3.4.6 "Early smoking machines"

It has been reported that some of the very early smoking machines used a column of water to generate the puff and that termination was done manually by removal of the burning cigarette when the glowing coal reached a certain point on the cigarette. A patent for a smoking machine was registered with the USPO as far back as 1941 and was based on a suction pump which pulled smoke from the cigarette and then, by means of a mechanical valve and gears, directed the cigarette smoke into a gas analyser chamber on the exhaust stroke of the pump. The puff duration was 2 s and the frequency was once every 30 s. Alas the puff volume does not seem to be given in the patent. Another patented device was designed to compare different types of cigarettes, e.g. plain and filtered brands.[15] By 1969, a recognizable rotary machine had been patented and had been designed so that all the first puffs from a set of cigarettes would be collected on one filter, all the secondary puffs on another filter, and so on.[16]

3.4.7 Selecting appropriate parameters

The selection of suitable values for smoking machine parameters was largely a pragmatic exercise based on a few smallish surveys of smokers and taking into account smoking machine capabilities which at that time were fairly limited. Advances in technology, developing knowledge of the analytical method, method validation and collaborative studies led to the introduction of standards to allow for conditioning of cigarettes, setting up the smoking machine to produce a bell shaped puff profile (some of the original machines worked on constant flow rather than constant volume), etc. The desire to measure smoke yields consistently and the additional requirement to determine carbon monoxide yields meant that air flows needed to be controlled and to this day there is a slightly different approach between ISO and the FTC as to the best way of achieving this.

For ISO smoking conditions, an airflow meter is placed in the position where a cigarette would burn within the smoking fume hood. The standard requires an air velocity value of 200 mm s^{-1} ± 50 mm s^{-1} per individual channel and a mean of 200 mm s^{-1} ± 30 mm s^{-1}. FTC smoking airflow is set at the minimum required to remove side-stream smoke without appreciably increasing static burn rate. This can be checked with a reference cigarette, e.g. Kentucky Reference 2R4F, which would be smoked to determine the proper airflow rate had been set by comparison to historical control data.

3.4.8 The requirement for reproducible results

The early selection of methods and smoking regimes had been done on an individual country basis. ISO asked CORESTA to carry out method validation studies and collaborative trials to improve and standardize the method. Following on from this work a set of ISO standards were issued in 1991, e.g. Determination of total particulate matter ….. using a … smoking machine.[17] The adoption by the European Economic Community of a 15 mg "tar" ceiling on all cigarette brands sold in 1993 in Europe meant that (a) laboratories from different countries would need to use the same validated method to determine the tar and nicotine yields in cigarette smoke and (b) the method had to be reproducible — it

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would not be acceptable for a cigarette brand tested in the UK to pass yet the same brand/production batch tested in Germany to fail.[18]

The work by CORESTA demonstrated the need for laboratories to have good Quality Assurance procedures, for example accreditation under ISO/IEC 17025[1] by a national "authorative body" (e.g. UKAS). Laboratories also needed to show their methods are reproducible by e.g. taking part in a proficiency testing scheme. The latest set of results from the South East Asia Collaborative Study (Round 12, 2004, 49 participants) showed that most laboratories can achieve good smoke nicotine yields (in terms of repeatability and reproducibility) when smoking the CORESTA CM4 monitor cigarette using ISO standards. The yearly CORESTA collaborative trials shows that there has been an improvement with time of the variability between laboratories as good practice has been disseminated between participants (e.g. the harmonization of air flows for different types of smoking machines).

3.4.9 How was the data to be used?

When the ISO smoking regime was first introduced, cigarettes were markedly different from those manufactured today in terms of smoke yield. In the 1972 UK survey of about 110 cigarette brands,[19] only 5 brands had a tar yield of less than 10 mg/cig. (the current maximum permitted yield in the European Union) and 10 brands exceed 30 mg/cig. — the highest being 38 mg/cig. Plain cigarettes were much more prevalent, filters were relatively simple devices and filter ventilation was in its infancy — the median tar value was 20 mg/cig. The purpose of testing cigarette brands was to allow ranking of brands and provide consumers with information to make a choice. Information provided from the UK study included the following:

"The brands are listed in the order of "tar" yield ....Differences between brands of up to 2 mg of "tar" can generally be ignored.....There are good grounds for believing that those smokers who choose to continue smoking are rather less likely to damage their health if they smoke cigarettes with a low "tar" yield."[19]

It was realized with time that the parameters chosen were not "... reflecting average human behaviour and leading to published yields universally under estimating yields actually obtained by the average smoker".[19]

The response from the UK Department of Health (DHSS) was "... that values presented in tables ... have never been intended to be actual yields obtained by any one smoker. Rather, they enable brands to be ranked."[20]

Similar points had been previously made in the 1967 FTC press release in the US stating the purpose of the FTC method:

The test method was not designed "to determine the amount of "tar" and nicotine inhaled by any human smoker, but rather to determine the amount of tar and nicotine generated when a cigarette is smoked by a machine in accordance with prescribed method." [19] The objective was to provide smokers with information that would allow them to switch to a lower tar brand.

3.4.10 The problem of using the data in a meaningful manner

In 1994 the FTC method was reviewed by an ad hoc expert committee which made several recommendations and comments about the difficulty of using smoking machine data effectively in informing the public of the relative risk of smoking different brands.

"The question involved in the purpose, methodology, and utility of the FTC protocol are complex medical and scientific issues that require ongoing involvement of Federal health agencies, including ...."

"A reduction in *machine-measured* tar yield from 15 mg tar to 1 mg tar does not reduce relative risk from 15 to 1".

"Information from the testing system is useless to smokers unless they have ready access to it."

"The available data suggests that smokers misunderstand the FTC test data".

It should be remembered that smoking yields vary with the design of the cigarette and under the conditions in which the cigarette is smoked. This variation is complex and so cannot be accurately predicted from a single smoking regime.

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3.5 What are smoking regimes currently used for?

The smoking regimes are used for several different purposes:

a) Manufacturers use the smoking regime to determine e.g. tar, nicotine and carbon yields in cigarette smoke when the product is smoked to the prescribed conditions. This information is used to make a declaration about the product. In the European Union, there is a requirement to print the tar, nicotine and carbon monoxide smoke yields on the side of the packet. In some countries there is an agreement to declare other analyte yields in cigarette smoke; e.g. in Canada there is now a requirement to declare benzene, formaldehyde and hydrogen cyanide yields.

b) Regulators use the smoking regime to verify the packet declaration. In addition, counterfeit cigarettes are a significant problem in some countries. Regulators use the smoking regime to test the suspect goods with a view to putting the counterfeiter on trial for making a false declaration.

c) Public health bodies use data obtained from testing cigarettes to disseminate information about the risks of smoking cigarettes. In many countries, legislators have established a regulatory limit above which cigarette smoke yields must not exceed when smoked under prescribed conditions.

d) Manufacturers use the smoking regime to compare brands in terms of smoke yields. This information is put on the side of the packet and until recently often with a descriptor (e.g. “lights”) to tell the consumer something about the product. Which smoking regime (if any) is most appropriate for ranking brands and how the information can be presented in a meaningful way to consumers is a contentious issue between manufacturers’ and health authorities at the present time.

e) Manufacturers use the smoking regime to evaluate the effect of product design. For example, if a new type of filter is introduced, then a manufacturer will test the product to see what effect it has on TNCO yields. Using a range of smoking regimes allows the manufacturer to explore the effects of changes in cigarette design on smoke yields under different conditions. If the smoking regimes chosen reflect e.g. common and maximum smoking parameters then the test results produced will lead to a better understanding of how human smoking behaviour influences smoke yields.

f) Manufacturers use the smoking regime as part of their Quality Control, to ensure that changes in tobacco blend or the manufacturing process does not have a significant effect on the product.

g) Manufacturers and others[22] have used smoking regimes to determine a range of analyte yields in cigarette smoke. The results can be used in many ways, e.g. (a) comparison of analyte yields (e.g. carbon monoxide and benzene) from one brand of cigarette; (b) ranking of brands by analyte yield and (c) comparison of analyte yields when using different smoking regimes.

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Table 1 — Smoking regimes in use today

Regime	ISO [a]	FTC	Massachusetts	Canadian Intense
No. of cigarettes smoked per pad	Max TPM 30 mg cig^{-1}			
Linear (44 mm Ø) Rotary (92 mm Ø)	5 20	5 20	3 10	3 10
Puff volume	35 ml ± 0,3 ml	35 ml ± 0,5 ml	45 ml ± 0,5 ml	55 ml ± 0,5 ml
Puff duration	2 s ± 0,05 s	2 s ± 0,05 s	2 s ± 0,05 s	2 s ± 0,05 s
Puff frequency	60 s ± 0,5 s	60 s ± 0,5 s	30 s ± 0,5 s	30 s ± 0,5 s
Ventilation holes	Open	Open	50 % blocked	100 % blocked
Conditioning atmosphere	60 % RH ± 3 % RH 22 °C ± 1 °C min 2, max 10 d	60 % RH ± 2 % RH 23,9 °C ± 1,1 °C [b] min 1, max 14 d	60 % RH ± 2 % RH 23,9 °C ± 1,1 °C min 1, max 14 d	60 % RH ± 3 % RH 22 °C ± 1 °C min 2, max 10 d
Smoking environment	60 % RH ± 5 % RH 22 °C ± 2 °C	60 % RH ± 3 % RH 23,9 °C ± 2°C	60 % RH ± 3 % RH 23,9 °C ± 2 °C	60 % RH ± 5 % RH 22 °C ± 2 °C
Air flow Linear ind. Port Linear avg. & Rotary [c]	 200 ± 50 ml min^{-1} 200 ± 30 ml min^{-1}	Sufficient to exhaust smoke – about 120 ml min^{-1}	Sufficient to exhaust smoke – about 120 ml min^{-1}	200 ± 50 ml min^{-1} 200 ± 30 ml min^{-1}
Butt length (whichever is the highest value)	Tipping + 3 mm or filter + 8 mm or 23 mm from butt	Tipping + 3 mm or 23 mm from butt	Tipping + 3 mm or 23 mm from butt	Tipping + 3 mm or filter + 8 mm or 23 mm from butt

a A very similar smoking regime to ISO is used in Japan, the only significant difference being that the minimum butt length is 30 mm or tipping plus 3 mm. It has been reported [16] that Japan is likely to change to the ISO Regime in 2002 but the author has been unable to confirm this change. The CORESTA smoking regime is identical to the ISO smoking regime.

b 23,9 °C is equivalent to 75 °F.

c FTC and Massachusetts smoking regimes only make reference to linear smoking machines.

3.6 Smoking machine capabilities

Tar, nicotine and carbon monoxide yields are normally determined by machine smoking. Machines have improved dramatically since the first machine was patented in 1941. Basically two types of smoking machines are used: linear and rotary machines. Depending on the aim and the analytes to be determined by the smoking test, each type presents advantages and disadvantages.

There are two major manufacturers of smoking machines in the world: Borgwaldt KC GmbH and Cerulean plc. Both manufacturers have designed at least two types of machine, one targeted at TNCO smoking where a high throughput is required and one machine which allows for greater flexibility and can be used for a wide range of applications.

Smoking machines produced by both manufacturers are capable of smoking to the three main regimes.

3.6.1 Puff volume

Earlier models of smoking machines used a 50 ml glass syringe designed to deliver a 35 ml puff volume. This could be adjusted to deliver a 45 ml puff volume but a 55 ml puff volume required either the use of a larger syringe or combining two channels together so that the volume drawn by two adjacent syringes are combined. Older models normally have to be modified to deliver a larger puff volume, e.g. moving the bar on the linear smoking machine.

On newer versions of smoking machines, the puff volumes can be varied quite easily by means of software and smoking machines are capable of producing a puff volume greater than 55 ml. However, the mechanics of the system means that it becomes increasingly more difficult to deliver larger volumes in a short period of time with good precision. Therefore, for example, a 100 ml puff volume with a 1 s puff duration is not practicable with the current design of smoking machines.

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3.6.2 Puff interval

The design of the rotary smoking machine means that it is only practicable to select a puff interval of 60 s when smoking 20 cigarettes. If the rotary smoking machine is used in 10 cigarette mode with a puff duration of 2 s, then the minimum puff frequency cannot be less than 30 s, i.e. a 2 s puff duration with a 1 s puff interval.

3.6.3 Puff duration

Puff duration is the parameter most difficult to reduce. It takes a certain amount of time to operate the syringe/piston drive in a smooth motion, open and close valves and produce a bell shaped profile. The piston then has to return to its original position ready to take the next puff. Therefore, a large puff volume combined with a short puff duration might require some fundamental design changes by the smoking machine manufacturer.

3.6.4 Butt length termination

Originally butt length determination was performed by the glowing end of the cigarette burning though a cotton thread which released a micro switch to terminate the smoking of the cigarette. There is a small time lag between the glowing coal reaching the butt length and the smoking of the cigarette being terminated. More sophisticated equipment tends to be used today, normally based on an infrared sensor which detects when the hot coal has reached a certain point along the length of the cigarette.

3.6.5 Air flows and puff profile

Air flows are much better controlled than when smoking machines were originally designed and enclosing the smoking machines in a box/hood means that adjustment of air flow over the cigarette is relatively easy to set up and adjust. Advances in software and the control systems mean that it is an easy matter to set up a puff profile, bell shaped being the most common type.

3.6.6 Ventilation hole blocking

There is a concern by workers in the field that whereas full blocking of ventilation holes to smoke to the Canadian Intense smoking regime is easy to perform in a reproducible manner, sealing 50 % of the ventilation holes to achieve the conditions required for the Massachusetts smoking regime can be much trickier and is currently impracticable if large volumes of cigarettes have to be tested.

NOTE It is relatively easy to achieve 100 % ventilation blocking by taping the cigarettes but it is difficult to achieve e.g. 50 % vent blocking consistently, in particular for different size diameters of cigarette brands.

A new type of holder could be designed by the smoking machine manufacturers to achieve partial ventilation blocking. NB There would need to be a sufficient market for the holders to cover production costs (i.e. a new ISO standard will be produced making partial ventilation blocking a requirement). The smoking method using the new style of holder would need to undergo validation, probably by means of a collaborative trial, to ensure that acceptable reproducibility between laboratories is achieved. The whole process from design of the new holder and its manufacture through to final validation would take at least a year to set up.

3.6.7 Trapping system

Total particulate matter in mainstream cigarette smoke is invariably trapped using a Cambridge glass fibre filter pad and the vapour phase component (containing the carbon monoxide) trapped in "gas-collection" bags for later analysis. Larger puff volumes and more puffs per min would mean a large increase in NFDPM yield with a significant chance of overloading the pad so that breakthrough would occur for the higher "tar" yielding cigarettes (e.g. > 30 mg cig^{-1}). This can be addressed in two ways — use a larger pad if the design of the smoking machine allows enough room to fit larger holders or reduce the number of cigarettes smoked per determination. The latter may well lead to poorer precision in analyte yields as there is less chance that "random variations" in the sample and the smoking process

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will be averaged out. The large volume of cigarette smoke generated by longer cigarettes may exceed the capacity of the bag but a simple solution is to fit larger bags to the smoking machine.

3.6.8 Other types of smoking

Following the introduction of ISO 15592-3[2] for smoking of fine-cut smoking articles, both smoking machine manufacturers have introduced a holder that complies with the standard. Except for conditioning and butt length and the holder, other parameters remain the same as in ISO 3308.

The demand for smoking to determine analytes yields other than TNCO has grown significantly over the last couple of decades. Smoking machine manufacturers have therefore developed machines which allow for different types of trap to catch the analyte under investigation, e.g. impingers can be used to trap volatile components in cigarette smoke.

There is not yet a standard for smoking other materials containing tobacco though eventually there may be a requirement for smoking Moassel products using a standardised Hookah pipe and FCSA containing a prescribed mixture of tobacco and cannabis resin to allow for a semiquantitative comparison of smoke yields with cigarette smoking. It is not envisaged that it would be practicable to set up a smoking regime for pipe tobacco or bidis.

Similarly the demand for side-stream measurements has meant that both manufacturers are looking to design an effective way of measuring side-stream on a regular basis using a routine analytical smoking machine if the demand is there.

3.7 A look into the future

The additional flexibility that new smoking machines allow, means that some investigatory work is now being performed by researchers to see what effect a range of smoking "conditions" have on tar, nicotine and carbon monoxide yields. This may be linked to observed human smoking behaviour that has been observed and "quantified" or to intake studies, e.g. measuring the amount of nicotine that is being trapped by the cigarette filter when smoked by a consumer.

3.8 Smoking regimes (historical)

Previous smoking regimes	Parameters
Tobacco Research Council	Puff volume 35 ml
	Puff duration 2 s
	Puff frequency one a minute
	Butt length 20 mm for untipped cigarettes; 20 mm for tipped cigarettes or length of paper + 2 mm; 23 mm or overwrap + 2 mm for tipped cigarettes over 80 mm in length,
	(air flows set and measured in tri duct, different style holder, cigarettes conditioned but smoking environment not conditioned)
Federal Trade Commission	23 mm; length of filter and overwrap + 3 mm if the total exceeds 23 mm
CORESTA	23 mm for untipped cigarettes, 23 mm or the length of the filter plug plus 8 mm or length of overwrap plus 3 mm - whichever is the longer.

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Health Canada	Puff volume 56 ml
	Puff duration 2 s
	Puff frequency 28 s
	Butt length 20 mm for untipped cigarettes; 20 mm for tipped cigarettes or length of paper + 2 mm; 23 mm or overwrap + 2 mm for tipped cigarettes over 80 mm in length
	Ventilation holes blocked
	(air flows set and measured in tri duct, different style holder, cigarettes conditioned but smoking environment not conditioned)
Massachusetts	(proposed 'heavy smoker' regime)
	Puff volume 60 ml
	Puff duration 2 s
	Puff frequency 26 s
	Ventilation holes blocked
	(proposed 'average smoker' regime)
	Puff volume 45 ml
	Puff duration 2 s
	Puff frequency 34 s
	Ventilation holes 50 % blocked

4 Summary of literature data on smoking topography

4.1 Abstract

One aspect of smoking behaviour has been termed smoking topography, i.e. the way smokers puff on a cigarette. Literature on smoking topography (1956 – 2004) was reviewed, focusing on parameters such as puff volume (individual and total), puff duration, puff interval, and number of puffs from a given cigarette, and how they may vary with cigarette "tar" yield, as determined by ISO/FTC machine smoking. Forty-six reports were identified as containing viable data, from which 100 data sets were extracted.

Significant differences in human puffing behaviour and ISO/FTC machine smoking parameters were found. When data were grouped according to machine-smoked ISO/FTC cigarette "tar" yield ranges (≥14 mg, 8 mg to < 14 mg, 3 mg to < 8 mg, and < 3 mg), puffing intensities increased as "tar" yield decreased.

Mean puff volume is larger than the 35 ml used in ISO/FTC testing. The overall mean was calculated as 48,3 ml. The mean puff volume increased from 48,1 ml, 47,8 ml, 54,7 ml, 57,2 ml, for cigarette ISO/FTC "tar" yields of ≥ 14 mg, 8 mg to < 14 mg, 3 mg to < 8 mg, and < 3 mg, respectively. The reported total puff volume increased from higher "tar" to lower "tar" yield cigarettes. The overall mean was calculated as 658 ml. The mean total puff volume increased from 567 ml, 611 ml, 817 ml, 890 ml, for cigarette ISO/FTC "tar" yields of ≥ 14 mg, 8 mg to < 14 mg, 3 mg to < 8 ,g, and < 3 mg, respectively. The mean puff interval for all "tar" groups was less than the 60 s used in ISO testing; the overall mean was calculated as 26 s (range: 11 s to 53 s; 10th %ile 18 s, 90th %ile 38 s).

In addition to the large diversity in smoking behaviour, there is a complex relationship between puffing parameters, smoke constituent yield, smoke intake (i.e. mouth level exposure), and smoke constituents uptake. This Technical Report contributes to bridge the gap between potential smoke intake and existing machine smoking methods.

4.2 Introduction and methods

A survey of 160 publications from the scientific literature (1956 – 2004) was conducted for the purpose of extracting information on the way cigarettes are smoked by adult smokers. These publications

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were initially identified using subject-search software and Philip Morris International literature files. Parameters such as puff volume (individual and total), puff duration, puff interval and number of puffs from a given cigarette, and how they may vary with cigarette "tar" yield as determined by ISO/FTC machine smoking, were of primary interest, and were entered in an Excel® spreadsheet[1)]. Any other parameters that were reported were recorded. A variety of devices for measurement of the puff parameters were used in these studies. Detailed discussion of methods and procedures used in each study is beyond the scope of this summary.

The first step was to develop criteria to determine whether a report dealing with the topic of smoking topography contained useful information. Some publications were identified by the search software based on limited mention of smoking behaviour, but included no data. Only reports that contained numerical data were used, and in no case were graphical presentations of data interpolated into numeric values. Data were not taken from studies in which the subjects were part of a short-term "switching" study or were required to smoke cigarettes of different "tar" yields from their usual brands. Studies were not included in which smokers had been deprived of smoking for more than a few hours before data were collected, or in which subjects were asked to take any drugs or other substances unless baseline data were available. Most of the reports were derived from laboratory settings where "topography devices" had been used, and therefore, the influence of blocking ventilation holes cannot be assessed. There is evidence suggesting that smoking in laboratory settings yields about 30 % higher smoke deliveries that smoking under "natural" conditions. Puff concatenation was not considered.

Using these criteria, 45 reports were identified as containing viable data. However, only one publication was available reporting topography data of subjects smoking cigarettes with < 3 mg "tar" delivery. The ad hoc group decided to accept unpublished data sets adding topography data from 250 smokers to this particular "tar" category (see references[32] and,[33] Dixon 2004 a, b), increasing the total number of reports to 47. Some reports contain multiple sets of data, and the total number of data sets extracted was 100. The total number of subjects n in the data sets were n = 2 432.

Not all of the publications reported results for all of the parameters of interest. ISO or FTC "tar" ranges for the cigarettes used were available in only some of the publications, and sometimes cigarette descriptors included "low nicotine," "medium nicotine," "low tar," "medium tar" or similar. Data summarized here were taken from the publications shown in 3.5.

NOTE Forty-seven reports are listed in 3.5, but only 46 were used (Guyatt 1989a and 1989b) containing data from the same study.

Publications that were considered but not used are shown in the bibliography. Table 9 provides a condensed version of the spreadsheet that was used.

4.3 Results

Table 2 shows a summary of the puff volume and puff number data including a breakdown by "tar" range. The data reported in the literature are generally mean values with varied types of associated statistics. In the tables below, a mean value is the mean of the means reported in the literature and standard deviation is that in those means. Puff number is the number of puffs taken by the smoker on a single cigarette. The "tar" values are a mixture of ISO and FTC machine-smoked values. Puff volume is the volume of individual puffs in millilitres (ml), whereas total puff volume is the total volume puffed from a cigarette (ml). These data provide an overview of the puff volume and puff number for cigarettes of different machine-smoked "tar" yield ranges. These groupings are somewhat arbitrary and other group definitions could be considered. Some adjustment was made to the "tar" range values to attempt to balance the number of studies in each category.

1) Available upon request via the Secretariat of ISO/TC 126

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Table 2 — Summary of puff volume and puff number data

"Tar" yield	Number of reports	Mean number of puffs	Mean puff volume (ml)	10th %ile puff volume (ml)	90th %ile puff volume (ml)	Mean total puff volume (ml)
All data	46	13,2	48,3	35,6	63,5	658
≥ 14 mg	14	12,5	48,1	37,7	63,5	567
8 –< 14 mg	10	12,3	47,8	41,0	55,7	611
3-8 mg	10	14,6	54,7	43,8	66,3	817
< 3 mg	3	15,3	57,2	48,4	63,3	890

NOTE Some of the reports did not specify the "tar" yield of the cigarettes used. The mean total puff volume (reported) is the mean of the values reported in individual publications.

Table 3 shows the topography data that were available from 14 reports for cigarettes in the FTC/ISO "tar" range of ≥ 14 mg.

Table 3 — Topography data for cigarettes ≥ 14 mg "tar"

	Mean number of puffs	Mean puff volume (ml)	Mean puff interval (s)	Mean puff duration (s)	Mean total puff volume (ml)	Mean number of puffs × mean puff volume (ml)
Mean	12,5	48,1	26,1	1,9	567	597
SD	1,3	10,7	8,8	0,4	152	160
Median	12,1	46,5	25,6	1,9	524	528
Max	14,7	66,0	40,7	2,6	872	950
Min	10,8	26,0	13,3	1,3	345	401
10th %ile	10,9	37,7	17,3	1,4	407	462
90th %ile	14,2	63,5	39,2	2,3	735	782

NOTE The mean total puff volume (reported) is the mean of the values reported in individual publications. The mean number of puffs × mean puff volume is the mean of the product of the number of puffs times the puff volume for those publications that reported both. Because some publications reported one of the parameters but not the other, the values in the two columns are not identical.

Table 4 shows the topography data that were available from 10 reports for cigarettes in the FTC/ISO "tar" range of 8 mg to < 14 mg.

Table 4 — Topography data for cigarettes 8 mg to < 14 mg "tar"

	Mean number of puffs	Mean puff volume (ml)	Mean puff interval (s)	Mean puff duration (s)	Mean total puff volume (ml)	Mean number of puffs × mean puff volume (ml)
Mean	12,3	47,8	27,3	1,8	611	595
SD	2,2	6,3	8,7	0,3	154	164
Median	12,6	46,6	24,7	1,8	598	590
Max	16,1	56,7	53,0	2,3	890	913
Min	7,0	37,1	20,8	1,2	344	329
90th %ile	14,9	55,7	39,0	2,1	833	815
10th %ile	9,4	41,0	21,0	1,5	473	402

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Table 5 shows the topography data that were available from 10 reports for cigarettes in the FTC/ISO "tar" range of 3 mg to < 8 mg.

Table 5 — Topography data for cigarettes 3 mg to < 8 mg "tar"

	Mean number of puffs	**Mean puff volume** (ml)	**Mean puff interval** (s)	**Mean puff duration** (s)	**Mean total puff volume** (ml)	**Mean number of puffs × mean puff volume** (ml)
Mean	14,6	54,7	22,6	2,0	817	818
SD	3,0	9,7	7,1	0,3	247	275
Median	13,6	54,3	21,6	2,0	705	723
Max	18,6	70,3	35,2	2,6	1292	1308
Min	9,9	36,0	11,0	1,6	563	460
90th %ile	18,4	66,3	32,6	2,3	1183	1215
10th %ile	10,8	43,8	15,8	1,7	600	540

Table 6 shows the topography data that were available from 3 reports for cigarettes in the FTC/ISO "tar" range of < 3 mg.

Table 6 — Topography data for cigarettes < 3 mg "tar"

	Mean number of puffs	**Mean puff volume** (ml)	**Mean puff interval** (s)	**Mean puff duration** (s)	**Mean total puff volume** (ml)	**Mean number of puffs × mean puff volume** (ml)
Mean	15,3	57,2	18,9	1,9	890	889
SD	2,7	8,9	0,7	0,1	189	267
Median	15,1	60,4	18,7	1,9	873	909
Max	18,8	63,4	19,7	2,0	1135	1192
Min	12,3	44,5	18,3	1,7	678	547
90th %ile	17,7	63,3	19,5	2,0	1065	1121
10th %ile	13,1	48,4	18,4	1,8	728	642

Table 7 shows a breakdown of the basic topography data with respect to the decade of publication.

Table 7 — Summary of topography by decade of publication

	Number of data sets	**Mean number of puffs**	**Mean puff volume** (ml)	**Mean puff interval** (s)	**Mean total puff volume** (ml)
All data	100	13,2 ± 2,6	48,3 ± 0,8	25,7 ± 8,1	657 ± 197
1970 – 1980	4	10,9 ± 1,1	38,5	36,8 ± 8,7	n/a
1981 - 1990	38	13,7 ± 2,7	44,9 ± 12,4	25,7 ± 7,9	568 ± 158
1991 - 2000	38	12,5 ± 2,5	50,0 ± 9,7	26,8 ± 8,6	673 ± 208
2001 - 2005	16	14,6 ± 2,0	53,0 ± 7,9	21,4 ± 1,9	784 ± 166

NOTE No numeric data were found prior to 1978. Only one puff volume was reported in the period 1970 – 1980, so no standard deviation could be calculated. Mean total puff volume is the mean of the product of puff volume and number of puffs for each study. This value is used rather than the mean of the reported total puff volumes to make use of additional data when total puff volume was not reported. n/a: data not available.

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Table 8 shows a breakdown of the basic topography data with respect to the geographic locations of the subjects.

Table 8 — Summary of smoking topography by geographic location of the subjects

	Number of data sets	Mean number of puffs	Mean puff volume (ml)	Mean puff interval (s)	Mean total puff volume (ml)
All data	100	13,2 + 2,6	48,3 ± 10,8	25,7 ± 8,1	657 ± 197
Americas	42	12,0 ± 1,9	50,9 ± 10,5	28,7 ± 9,3	624 ± 152
Europe	58	14,0 ± 2,7	46,8 ± 10,9	24,7 ± 7,2	683 ± 221
NOTE Americas includes studies from the United States, Canada and Brazil. Europe includes EU countries and Switzerland.					

4.4 Discussion and conclusions

Because of inconsistencies in the way that "tar" values are reported in the literature (ranges, approximate values, etc.), and especially because of the limited data available for the low "tar" cigarettes, it is difficult to perform statistical analyses on the relationships between "tar" and the smoking topography parameters. Correlation between FTC/ISO "tar," and the number of puffs, puff volume and total puff volume with case-wise deletion of missing data resulted in correlation coefficients (r) between "tar" and these parameters of – 0,36 (P = 0,009, N = 50), – 0,38 (P = 0,006, N = 51) and – 0,55 (P = 0,001, N = 46), respectively. All of the correlations are statistically significant (P < 0,05). The implication is that smoking intensity tends to increase as "tar" decreases.

The results of this literature survey may be summarized as follows:

— Mean puff volume is larger than the 35 ml used in ISO testing and may show increasing volumes from high to low "tar" cigarettes. The overall mean was calculated as 48,3 ml. The mean puff volume increased from 48,1 ml, 47,8 ml, 54,7 ml, 57,2 ml, for cigarette "tar" yields of ≥ 14, 8 mg to < 14 mg, 3 mg to < 8 mg, and < 3 mg, respectively.

— The mean reported total puff volume increased from higher "tar" to lower "tar" yield cigarettes. The overall mean was calculated as 658 ml. The mean total puff volume increased from 567 ml, 611 ml, 817 ml, 890 ml, for cigarette "tar" yields of ≥ 14, 8 mg to < 14 mg, 3 mg to < 8 mg, and < 3 mg, respectively.

— The mean number of puffs may slightly increase from higher "tar" to lower "tar" yield cigarettes. The overall mean number of puffs was calculated 13,2.

— The mean puff interval for all "tar" groups was less than the 60 s used in ISO testing; the overall mean was calculated as 26 s (range: 11 s – 53 s; 10th %ile 18 s, 90th %ile 38 s).

— Lastly, there is considerable variation between smokers in the way cigarettes are smoked.

Using the information summarized here, estimates of cigarette smoke constituent yield more closely reflecting smoker behaviour than obtained from ISO machine-smoked results may be feasible. It should be pointed out that the puffing parameters are not independent and that a change in one parameter could directly influence other parameters.

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Table 9 — Condensed spreadsheet of topography data — All data

All data																				
Region	Year	First author	Gender 0 = Both 1 = Male 2 = Female	Method of topography Measurements 1 = Plowshare 2 = Pickens 3 = Stratham PM5TC 4 = Other 5 = Creighton 6 = CGC Ltd 7 = Filtrona SAP4	N	Cig/ Day	ISO/FTC Tar range		ISO/FTC Nicotine range		Nicotine delivery method 1 = Butt 2 = NE 3 = Other	Tar deliv-ery (mg/ cig.)	Nico-tine deliv-ery (mg/ cig.)	% Vent.	Mean no. of puffs	Mean puff vol-ume (ml)	Mean puff inter-val (s)	Mean puff dura-tion (s)	Mean total puff volume (meas-ured) (ml)	Calc. mean No. of puffs x mean puff volume (ml)
EU	1978	Guillerm	0	4	8			30,9	1,66						12,0	38,5	40,7	1,85		462
EU	1978	Ashton			8				1,00		1		0,969				24	1,47		
EU	1978	Rawbone		4	5						1		0,53		9,8		43,6	1,74		
EU	1978			4	7						1	•	0,78		10,9		38,8	1,92		
EU	1982	Battig	1	5	67	22		11,8	0,86	± 0,33					12,1	43,7	24,8	2,28	528	529
EU	1982		2	5	43	21		11,0	0,79	± 0,29					13,0	37,1	24,7	1,99	481	482
EU	1982	Russell	0		12	38	12,0	19,0	1,10	1,50					14,7	39,8	25,6	2,30	547	585
US	1983	Gritz	1	4	8	28				1,10					9,5	65,6	47,2	2,20	600	623
US	1983	Herring			11					1,03	3		1,42		13,1	43,3	35,0	1,65		565
US	1983	Gust		4	8										9,0	43,7	48,4	1,60	380	393
EU	1983	Adams	0	4	10											44,2	25,9	1,88	614	
EU	1984	McBride	0	6	9						1		1,53		15,7	42,1	25,3	2,14		661
EU	1984		0	6	9						1		1,23		14,6	47,5	21,9	2,16		694
EU	1984		0	6	9						1		1,94		15,3	38,2	23,1	1,89		584
EU	1984	Hopkins	0		6			15,0		1,50	1		1,44			53,8		1,71	455	
EU	1984	Nil	2	6	10										14,8	41,1	25,9	1,67	619	608
EU	1984		2	6	10										14,7	39,5	25,7	1,57	579	581
EU	1985	Medici	0		17										13,7	43,1	18,7	2,20		590
EU	1985		0		10										15,3	36,9	20,5	1,90		565
EU	1985		1		7										19,3	35,7	16,1	1,60		689
EU	1985		0		15										14,0	30,7	18,2	2,10		430

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Table 9 *(continued)*

All data																				
Region	**Year**	**First author**	**Gender 0 = Both 1 = Male 2 = Female**	**Method of topography Measurements 1 = Plowshare 2 = Pickens 3 = Stratham PM5TC 4 = Other 5 = Creighton 6 = CGC Ltd 7 = Filtrona SAP4**	**N**	**Cig/ Day**	**ISO/FTC Tar range**		**ISO/FTC Nicotine range**		**Nicotine delivery method 1 = Butt 2 = NE 3 = Other**	**Tar deliv-ery** (mg/ cig.)	**Nico-tine deliv-ery** (mg/ cig.)	**% Vent.**	**Mean no. of puffs**	**Mean puff vol-ume** (ml)	**Mean puff inter-val** (s)	**Mean puff dura-tion** (s)	**Mean total puff volume (meas-ured)** (ml)	**Calc. mean No. of puffs x mean puff volume** (ml)
EU	1985		0		32										15,3	35,3	23,1	1,80		540
EU	1985		1		10										14,7	34,6	18,3	2,10		509
EU	1986	Nil	1	6	69	25		11,8		0,88					12,6	42,3	22,9	2,18	512	533
			2	6	48	24		9,8		0,71					12,5	41,4	21,7	2,02	510	518
E	1986	Nil, Woodson	0												12,7	30,3	28	2,20	376	385
US	1986	Hughes	0	2	19	24				0,90	3		0,9		11,9			1,58		
US	1986		0	2	27	21				−0,90	3		0,9		10,4			1,56		
EU	1986	Wood-man	0	7	9	22	16,0	18,0	1,30	1,50					14,0	47,2	19,6	1,90	417	661
US	1987	Hatsu-kami	0	2	12	29														
US	1987		0	2											13,4			1,16		
US	1987		0	2											11,1			1,38		
US	1987	Hatsu-kami	0												12,1			1,20		
EU	1987	Wood-man	0	7	10		9,0	18,0	0,90	1,50					12,1	43,6	24,1	1,90	520	528
EU	1987	Puustinen	0		8		4,0	5,0		0,32					18,4	36	11,0	2,20	649	662
EU	1987		0		8		14,0	15,0		0,97					13,6	26	13,3	1,80	345	354
US	1988	Hatsu-kami	0	2	10	35			0,60	1,15					15,3			1,30		
EU	1989	Nil	0	5	15				10,10	0,78					22,6	27,4	30,2		605	619
EU	1989	Guyatt	0	5	28	25									13,9	47,2	34,2	2,10	603	656
US	1990	Bridges	1		5				0,28	0,43					13,2	85,4	23,9	2,48	1142	1127

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