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Assessing secondhand smoke exposure with reported measures

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ABSTRACT

Non-smokers are exposed to tobacco smoke from the burning cigarette and the exhaled smoke from smokers. In spite of decades of development of approaches to assess secondhand smoke exposure (SHSe), there are still unresolved methodological issues. This manuscript summarises the scientific evidence on the use of SHSe reported measures and their methods, objectives, strengths and limitations; and discusses best practices for assessing behaviour leading to SHSe for lifetime and immediate or current SHSe. Recommendations for advancing measurement science of SHSe are provided. Behavioural measures of SHSe commonly rely on self-reports from children and adults. Most commonly, the methodology includes self, proxy and interview-based reporting styles using retrospective recall or diary-style reporting formats. The reporting method used will vary based upon the subject of interest, assessment objectives and cultural context. Appropriately implemented, reported measures of SHSe provide an accurate, timely and cost-effective method for assessing exposure time, location and quantity in a wide variety of populations.

INTRODUCTION

In this series of articles, three topic assessments summarising current knowledge about measuring secondhand smoke exposure (SHSe) are presented, covering self-reported measures, environmental measurements and biomarkers, and are based on a multidisciplinary expert meeting held in late 2008 at Johns Hopkins University, Baltimore, USA and supported by the Flight Attendant Medical Research Institute (FAMRI). The meeting addressed SHSe assessment approaches to provide uniform methods for FAMRI investigators and others, and to set the stage for innovation. The topic assessments reflect the course of discussion at the meeting, along with recommendations developed from meeting participants, who were established researchers in one of the three focus areas. This article presents scientific evidence on the use of reported measures of SHSe and their methods, objectives, strengths and limitations; and discusses best practices for assessing behaviour leading to SHSe, via self-report and other measures, for lifetime and immediate or current SHSe. Recommendations for advancing measurement science of SHSe are provided.

MODELS OF EXPOSURE

The microenvironmental exposure model has been adopted to frame assessments of behaviour leading

to SHSe. A microenvironment is a space with a volume (eg, a space in a home, office, school) in which the SHS concentration is 'spatially uniform' during some specific time interval.¹ The SHS concentration in a microenvironment, at a given time, results from the density of smoking in that environment, mediated by factors diluting or otherwise removing smoke from the air.² SHSe is expressed as the sum of exposures in the multiple microenvironments where a person spends time.^{1,3,4}

Aspects of the physical and social environments should be considered when developing a measurement tool as both are drivers of smoking and/or SHSe.⁵ Within defined microenvironments, the practices relating to production of SHSe, attenuation, or avoidance of smoke should be assessed over time and by microenvironment. Establishing specific time-activity patterns for the individual in question is important for accurate identification of times and locations of potential exposure. For example, as health-compromised children are likely to spend more time indoors than adults or healthy children, they may be at risk for SHSe. Younger children demonstrating higher hand-to-mouth behaviour may also be exposed to higher SHS residue (ie, 'third-hand smoke') on objects and surfaces.⁶ Collecting parental smoking history, family background, attitudes, family rules about smoking in the home, and social and community standards will lend insight into determinants of SHSe, which likely contribute to smoking behaviour and to whether smoking takes place in the individual's microenvironments, in public and private settings.

ASSESSING SHSE IN DIFFERENT SETTINGS

Clinical setting studies

Interviews or questionnaires administered in clinical settings assist doctors in identifying patients with SHSe who may benefit from counselling or other interventions. SHSe assessment is most important in children, non-smoking adolescents, young adults and in asthmatic populations or among those with chronic obstructive pulmonary disease. Lifetime exposure assessment in adults is critical for risk assessment for lung cancer and coronary heart disease, especially among high-exposure workers (eg, flight attendants, bartenders and waiters) and those who have lived with a smoker.

SHSe is generally measured by proxy (parent or other adult) for young and school aged; self-report for young children; and adolescents. For

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adolescents, the distinction between tobacco use and SHSe from others should be included. Ensuring confidentiality is critical to prevent disclosure of potentially illicit smoking behaviour by teens or their peers to their parents or guardians. SHSe assessment by doctors in a clinical setting, however, is often problematic because clinicians are charged to complete many tasks in a short period. SHSe assessment is not their priority, and they often feel undertrained about intervening in SHSe situations.⁷

Field and epidemiological studies

Assessing SHSe at the population level requires techniques that can be implemented in large samples. Study needs, however, may be addressed with simple, straightforward approaches if the goals are to measure exposure prevalence. Large population-based surveys, such as the National Health and Nutrition Examination Survey (NHANES), the Global Youth Tobacco Survey (GYTS), the International Tobacco Control (ITC) Surveys, the Global Adult Tobacco Survey (GATS) and smaller surveys with more focused populations of interest have assessed SHSe in the home and in public places including entertainment venues. Smoking restrictions and bans at home and in the community for microenvironments (eg, restaurants, bars, stores and outdoor environments) are important measures to collect. For example, the GATS, which has been implemented in more than 15 countries, includes detailed questions related about the rules of smoking inside the home and work. The inclusion of these SHSe questions should be guided by local smoke-free practices of the population of interest. These measures can be useful for smoke-free policies' implementation and compliance evaluation and thus be related to respondents as contextual variables in multilevel research designs.⁸

In epidemiological studies, a valid and reliable measurement of SHSe is fundamental to accurately assess disease risk, as inaccurate measurement of a person's exposure can lead to biased risk estimates² and is often cited as a major limitation of studies evaluating association between SHSe and disease. Understanding the nature of the misclassification is critical, as systematic measurement errors can bias risk estimates towards or away from the null, while random errors in exposure misclassification can diminish the exposure–risk relationship. In SHSe studies, where the hypothesised association between exposure and disease is anticipated to be modest, imprecise exposure measurement could lead to a conclusion that a real risk, while modest, does not exist (type 2 error). For SHSe in a population where a large number of people could be affected, even a modest disease risk has important public health implications.

When developing the questionnaire, its method of administration and cultural context for assessing SHSe must be considered. The use of culturally competent instruments and methods will help ensure accuracy by increasing the rate, validity and reliability of the responses.⁹ To maintain reliability and validity, the materials' language, microenvironments and administration must be contextually appropriate. Translated questionnaires should match the original in language, semantics, idioms, experiences and concepts.⁹ Questions about exposure to types of tobacco smoke other than cigarettes should be revised as appropriate.

REPORTED METHODS FOR ASSESSING SHSE

Questionnaires are the most common method of assessing SHSe because they are simple to administer and cost effective compared to biological markers and environmental monitoring.^{2 10} An added advantage is that individuals can report lifetime SHSe as

well as usual and current levels. While some studies also include measures of possible determinants of smoking or exposure behaviour, such as education or working outside of the home, these remain under development.^{11 12}

False reporting, or over/under-reporting, are potential limitations of using questionnaires and will vary depending on the cultural context of smoking and SHSe. However, these limitations are not unique to data obtained from questionnaires. For example, if participants switch urine samples to avoid biomarker detection, underascertainment results are similar to false reports of being a non-smoker. Cross-measurement correlations (eg, r = approximately 0.50) show relationships among reported smoking and reported child exposure that are roughly equivalent to 'objective' measures of nicotine or cotinine (a metabolite of nicotine used as a biomarker of SHSe), suggesting that no method is error free.^{13–15}

A participant's ability to recall SHSe episodes, including frequency and duration, may also be questionable.¹⁶ Recall accuracy in survey responses can be improved by reducing the timeframe between the discrete event and the length of the recall period¹⁶; for example, recall over the last 24 h would be more accurate than over 30 days or 6 months. The assumption, however, that events in the last 24 h represent a respondent's current experiences may be inaccurate, as that 24-h period may be atypical.^{5 17} Researchers need to balance between striving to achieve a respondent's accurate recall and the need to cover a longer period to obtain more representative SHSe estimates. To balance reporting accuracy against research requirements, we recommend a maximum 7-day recall period in a single assessment. However, useful long-term indicators reported with reasonable accuracy can include living with smoking parents, spouse, or other household members.

Another SHSe assessment method is a diary, which can provide participant's detailed exposure information within specific microenvironments. Diaries reduce the recall burden: as reporting occurs over the past day rather than the past week or month, the respondent knows what should be reported in the diary later that day and will likely notice and record instances of exposure as they occur.¹⁸ Direct observation (live or video recorded) with trained observers can increase objectivity, reducing the rate of false reporting. It is likely to provide more valid data due to focused attention by the trained data collector, whether an individual study participant or a study team member. If used together, diary and observational methods can be quite informative for respondents or microenvironments of particular interest or for providing comparison data to estimate measurement error.

ACCURACY OF QUESTIONS ASSESSING SHSE

Questions assessing SHSe should be valid and reliable (ie, accurate). Participants' answers to SHSe questions are deemed reliable if those answers are replicated or reproduced when the questions are repeated.¹⁹ Binary response (ie, yes/no) reliability can be measured using the κ statistic (the observed agreement beyond chance), while correlation coefficients can be used for continuous responses. In general, a κ value >0.75 , 0.40 – 0.75 and below 0.40 represents excellent, intermediate to good and poor agreement beyond chance, respectively.¹⁹ In interpreting Pearson's correlation coefficient, we refer to reliability as: none (0.0 to ± 0.09), low (± 0.1 to ± 0.29), moderate (± 0.3 to ± 0.49) and strong (± 0.5 to ± 1.0). Studies testing the validity of SHSe measurement questions assess the questions' ability to correctly identify those individuals truly exposed, along with exposure intensity.¹⁹ Acceptable 'gold standards' are environmental

measures, including airborne nicotine or respiratory particles, and biomarkers, such as cotinine. The relationship of the environmental measure with the questionnaire items will vary depending on time since peak exposure, level of continuous versus intermittent exposure, air sampling time frame and measured microenvironments.^{20 21}

Respondents may not realise that they have been exposed to SHS. For example, in NHANES 2003–2004, overall self-reported exposure prevalence was underreported as compared to serum cotinine, but the underreporting level depended on the exposure definition.²² For instance, 42% of non-smoking adults had detectable levels of cotinine, while only 5.4% reported exposure at home and 8.5% reported exposure at work. For home exposure measurement, one selected family member reported whether any household member smoked anywhere inside the home. SHSe classification at work was based on each participant's response to the number of hours per day that he or she could smell tobacco smoke.²² Thus, the specific nature of measures can lead to misclassification in exposure estimates.

To estimate total exposure, the survey respondent should recall and quantify exposure across different locations, length of exposure and its source. Instructing respondents on proper definitions and providing examples of events that qualify, as well as possible SHSe locations, improve recall accuracy.²³ Surveys intending to capture exposure intensity, estimated time of exposure, number of smokers generating SHS and proximity to smokers should include items addressing these factors specifically.²⁴

A comprehensive Medline literature search of English-language journals was conducted, covering January 1966 to 13 July 2010, and using the search terms 'tobacco smoke pollution (MESH terms) AND questionnaire AND (validat* OR Reproduc* OR reliab*)' for studies among humans. Of the 102 articles examined, 3 presented relevant information on questionnaire reliability; 5 others were identified through reference lists of included articles and reviews. A total of 45 validation studies were identified (air nicotine or particulate matter concentrations (13), measurements of hair nicotine (4) and cotinine (28)).

Reliability of questions assessing SHSe

Adults can reliably answer questions regarding SHSe (yes/no) from their parents during childhood ($\kappa \geq 0.82$), their spouse, household members, and if they are living with a spouse or mother who smokes (table 1).^{25–27} However, reliability sharply decreases for exposure from father, siblings, own children and other household members.²⁷ This includes responses related to years of SHSe to maternal ($r=0.69–0.76$), paternal ($r=0.75$) and other household members' smoking ($r=0.63$) during childhood, as well as for years of exposure by their spouse ($r=0.95$) or other household members ($r=0.78$) during adulthood.²⁶ Correlation coefficients ranged from 0.18 to 0.55 for hours per day.^{26–28}

Studies of the assessment of children's SHSe have reported good reliability using parents' self-reported smoking behaviour including amount, type of day (weekday/weekend) and place of exposure (table 2).^{18 29} Families of children with asthma ($n=91$) kept a 2-week diary recording cigarettes per day (CPD) smoked in the home, by type of day, at baseline and 2 months later.¹⁸ Overall, reliability was high for child's CPD exposed at home per week or during a typical workday, by all sources ($r=0.81$) and by the parents ($r>0.75$). Reliability was lower for parental CPD exposure at home on a typical non-workday ($r=0.63$). In another study, high test–retest correlations were obtained for questions about CPD smoked by the mother, total, or at home, either on weekdays or weekends ($r \geq 0.95$), when again repeatedly at

baseline, 3-month and 6-month interview.²⁹ Mothers of children with asthma gave highly reliable answers regarding CPD smoked while the child was present in the room or car with smokers ($r=0.69$).³⁰

The reliability of participants' answers to questions about their childhood and adulthood SHSe was compared with surrogates' responses. Surrogates included parents, siblings, spouses, other household members and coworkers. Good agreement was reported between the participants and surrogate responses in nearly all SHSe measures, including presence and number of smokers at home ($r \geq 0.67$), number of years exposed ($r \geq 0.89$) and an index of SHSe (severity \times years of exposure) ($r \geq 0.74$).³¹

Validity of questions assessing SHSe using environmental measurements

The number of smokers or of cigarettes to which non-smokers are exposed may be valid indicators of SHSe intensity (supplementary table S1). Several studies evaluating the correlation between number of cigarettes smoked in the home and air nicotine concentration also found strong correlation coefficients.^{29 32 33} Two studies of families of children with asthma, however, reported low or no correlation; both used air nicotine passive monitors.^{18 34} In a study of 254 non-smoking pregnant women wearing air nicotine passive monitors for 1 week, low to moderate correlations were found between total number of smokers or cigarettes to which the women reported exposure in the homes (0.34–0.35) and at work ($r=0.16–0.17$).³⁵ Strong correlation coefficients were reported for the number of smokers present or to whom the person was exposed at work ($r=0.61–0.67$)^{36–38} and the number of cigarettes smoked in a restaurant ($r=0.78$)³⁶ (supplementary table S2).

Two studies validated questions about SHSe intensity among children (supplementary table S3).^{18 29} Correlations between air nicotine measurements and the reported number of cigarettes to which the child (6–17 years old) was exposed and CPD smoked in the house ranged from 0.07 to 0.43.¹⁸ Responses from mothers of young children were moderately to strongly correlated with air nicotine levels measured with an active monitor.²⁹ Strong, nearly identical correlation coefficients were found between the number of cigarettes to which the child was exposed at home from the mother ($r=0.50–0.64$) and the number of cigarettes smoked inside the home per week by the mother ($r=0.65–0.84$).²⁹

Several studies have validated questions assessing the duration (hours or minutes) of SHSe using air nicotine concentrations (supplementary tables S1–S3).^{34 35 37 39 40} In these studies, the correlations were found non-existent to moderate. As questions about exposure location became more specific, the correlations became weaker. Specifically asking about the number of hours a child is exposed at home yielded low to moderate correlation coefficients in two other studies ($r=0.25–0.36$).^{34 40}

Coghlin evaluated the validity of a 7-day diary and a questionnaire against air nicotine among 19 non-smoking adults.²⁴ The strongest correlations ($r=0.91–0.95$) were found with an index based on information about the hours of exposure, number of smokers and their proximity to the participant (supplementary table S4).

Validity of questions assessing SHSe using biomarkers

Questions regarding children's SHSe and exposure intensity have been validated with the presence of nicotine and cotinine in hair (supplementary table S5).^{41–44} Al-Delaimy *et al* found that hair nicotine levels in children increased 10.5% per mother's

Table 1 Reliability of questions assessing secondhand smoke exposure (SHSe) among adults

Reference population	Assessment	Exposure time	Exposure source	Values		
SHSe status (yes/no)						
Coultas <i>et al</i> , 1989 ²⁶ : 149 participants aged 21–79 years asked 4–6 months apart asked if the source had smoked daily for ≥ 6 months	SHSe status	Pregnancy	Mother	$\kappa=0.73^{***}$		
		Childhood	Mother	$\kappa=0.87^{***}$		
			Father	$\kappa=0.85^{***}$		
Brownson <i>et al</i> , 1993 ²⁵ : 37 cases and 73 controls asked 1.7–1.9 years apart. All non-smoking women participants of a larger lung cancer study in Missouri.	SHSe status	Childhood	Parents	93.6%†, $\kappa=0.82$; SE=0.095		
			All household members	82.7%, $\kappa=0.60$; SE=0.090		
		Adulthood	Spouse	83.6%, $\kappa=0.67$; SE=0.095		
			All household members	80.0%, $\kappa=0.59$; SE=0.093		
Living with a smoker (yes/no)						
Pron <i>et al</i> , 1988 ²⁷ : 117 controls (63 females and 54 males) in a case-control study of lung cancer in Toronto asked 6 months apart	Ever living in a house with a regular smoker	Lifetime	Any	$\kappa=0.66$; SE=0.08 (females: $\kappa=0.61$; SE=0.12) (males: $\kappa=0.70$; SE=0.11)		
		Adulthood	Wife	N=53; $\kappa=0.89$; SE=0.064		
	Husband		N=61; $\kappa=0.89$; SE=0.059			
	Children		$\kappa=0.24$; SE=0.106			
	Mother		$\kappa=0.76$; SE=0.103			
	Father		$\kappa=0.44$; SE=0.077			
	Sibling		$\kappa=0.57$; SE=0.117			
	Other (relatives)		$\kappa=0.16$; SE=0.137			
	Other (non-relatives)		$\kappa=0.02$; SE=0.093			
	Duration of exposure Pron <i>et al</i> , 1988 ²⁷ : 117 controls (62 females and 53 males) in a case-control study of lung cancer in Toronto asked 6 months apart	Years of SHSe Living with a regular smoker	Lifetime	Any	$r=0.45$; 95% CI 0.29 to 0.58 (females: $r=0.46$; 95% CI 0.24 to 0.64) (males: $r=0.44$; 95% CI 0.19 to 0.63)	
Spouse				N=58; $r=0.25$; 95% CI -0.01 to 0.48		
Wife		N=22; $r=0.37$; 95% CI -0.06 to 0.68				
Husband		N=36; $r=0.20$; 95% CI -0.14 to 0.50				
Parent		N=40; $r=0.48$ 95% CI 0.20 to 0.69				
Mother		N=8; $r=0.69$; 95% CI -0.03 to 0.94				
Father		N=32; $r=0.46$ 95% CI 0.13 to 0.70				
Other (relatives)		N=17; $r=0.59$; 95% CI 0.15 to 0.83				
Coultas <i>et al</i> , 1989 ²⁶ : 149 participants aged 21–79 years asked 4–6 months apart		Years of SHSe		Childhood	Mother	N=33; $r=0.76$
					Father	N=57; $r=0.75$
	Years of SHSe sharing the home with smoker(s)	Adulthood	Others		N=26; $r=0.63$	
			Spouse		N=40; $r=0.95$	
	Hours per day of SHSe	Childhood	Other household members		N=67; $r=0.78$	
			Adulthood		Mother	N=31; $r=0.18$
Father				N=55; $r=0.54$		
Others				N=20; $r=0.51$		
Brownson <i>et al</i> , 1993 ²⁵ : 37 cases and 73 controls asked 1.7–1.9 years apart. All non-smoking women participants of a larger lung cancer study in Missouri.	Pack-years of SHSe	Childhood	Spouse	N=39; $r=0.25$		
			Other household members	N=58; $r=0.54$		
		Adulthood	All household members	60.9%, $r=0.71$		
			Parents	73.6%, $r=0.81$		
Intensity of exposure	Categorical cigarettes per day (<1, 1, >1 pack/day, or unknown)	Childhood	All household members	52.7%, $r=0.77$		
			Parents	73.6%, $r=0.81$		
			Spouse	60.0%, $r=0.80$		
	No. of smokers living in the home	Adulthood	Mother	N=48; $\kappa=0.22^*$		
			Father	N=79; $\kappa=0.04^*$		
No. of smokers living in the home	Adulthood	Spouse	N=64; $\kappa=-0.04^*$			
		No. of smokers living in the home	$r=0.5$			

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

†Percentage agreement.

 κ , kappa; r , correlation coefficient.

Table 2 Reliability of questions assessing current secondhand smoke exposure (SHSe) among children

Reference population	Assessment	Exposure source	Values	
Intensity of exposure				
Zakarian <i>et al</i> , 2004 ²⁹ : mothers with children aged ≤4 years recruited in a randomised controlled trial. The time between questions was immediate and repeated at baseline, 3-month and 6-month follow-up.	CPD: asked to report their smoking on typical days during the past 7 days	Mother	Weekday: $r=0.97-0.98$; weekend: $r=0.95-0.99$	
Emerson <i>et al</i> , 1995 ¹⁸ : 91 families with an asthmatic child 6–17 years old asked 2 months apart	CPD smoked at home: diary (2-week period)	Parents	Workday: $r=0.88$; non-workday: $r=0.60$	
Zakarian <i>et al</i> , 2004 ²⁹ : mothers with children aged ≤4 years recruited in a randomised controlled trial. The time between questions was immediate and repeated at baseline, 3-month and 6-month follow-up.	CPD smoked at home: in the past 7 days	Mother	$r=0.97-0.98$	
Emerson <i>et al</i> , 1995 ¹⁸ : 91 families with an asthmatic child 6–17 years old asked 2 months apart	Average CPD to which the child is exposed at home: diary (2-week period)	Not specified	$r=0.84$	
Matt <i>et al</i> , 2000 ²³ : 22 mothers of children <2.5 years old from an ethnically diverse sample of low-income, low-education families asked 2 months apart	Weekly no. of cigarettes smoked at home: in the past 7 days	Mother	$r=0.91$	
		Father	$r=0.87$	
Emerson <i>et al</i> , 1995 ¹⁸ : 91 families with an asthmatic child 6–17 years old asked 2 months apart	Weekly no. of cigarettes smoked at home	Parents	$r=0.86$	
		No. of cigarettes to which the child is exposed at home: diary (2-week period)	Workday: $r=0.82$; non-workday: $r=0.63$	
		Weekly no. of cigarettes to which the child is exposed at home	Parents	$r=0.76$
		All smokers	$r=0.81$	
Matt <i>et al</i> , 2000 ²³ : 22 mothers of children <2.5 years old from an ethnically diverse sample of low-income, low-education families asked 2 months apart	Weekly no. of cigarettes to which the child is exposed at home	All sources	$r=0.88$	
		Mother	$r=0.9$	
		Father	$r=0.81$	
		Parents and others	$r=0.88$	
Hovell <i>et al</i> , 2002 ³⁰ : 204 children with asthma 3–17 years old asked 5 days apart	No. of cigarettes smoked while the child was in the same room or car	All smokers	$r=0.69^{***}$	
Zakarian <i>et al</i> , 2004 ²⁹ : mothers with children aged ≤4 years recruited in a randomised controlled trial. The time between questions was immediate and repeated at baseline, 3-month and 6-month follow-up.	No. of cigarettes to which the child was exposed in the car	Mother	$r=0.90-0.93$	

* $p<0.05$; ** $p<0.01$; *** $p<0.001$.

†Percentage agreement.

CPD, cigarettes per day; κ , kappa; r , correlation coefficient.

CPD smoked inside the house.⁴¹ Smaller percentage increases were reported for smoking by the father or other adults. Hair nicotine levels in 112 children were highly correlated with CPD smoked by parents ($r=0.68$) or by household adults and visitors ($r=0.69$) inside the house.⁴² High correlations were also reported between hair nicotine concentration and the number of smokers living in the house.^{41–42} In a study of 72 young children, CPD to which a child was exposed was strongly correlated ($r=0.64$) with hair nicotine levels.⁴³ Woodruff *et al*, however, found a correlation of approximately 0.2 between the total number of cigarettes smoked in a child's presence in the past month and hair nicotine levels.⁴⁴ One possibility for this lack of correlation is poor recall of the number of cigarettes smoked in the child's presence, as well as length of time to recall (1 month). In a multicountry study, hair nicotine levels among children and non-smoking women increased with increases in number of smokers living in the household, father's CPD and if smoking was permitted in the house. Additionally, children's hair nicotine increased if their mother smoked and her CPD, as well as with number of smokers sharing the child's bedroom.⁴⁵ A study among non-smoking bar and restaurant workers showed higher hair nicotine levels with more sources of SHSe and higher values for those working in a bar.⁴⁶

Between 1989 and 2009, 23 studies reported on urine cotinine and SHSe among adults and children (supplementary table S6). Four of these studies validated SHSe metrics in adults, with all but one study restricted to non-smokers.^{26–35–37–47} Most of the studies found a low to strong correlation between SHSe and urine cotinine-to-creatinine ratio ($r=0.18-0.57$). Correlation coefficients were strongest when the SHSe question was more

specific.^{26–35} Cummings *et al* found no-to-low correlation between urine cotinine and SHSe using various metrics, including total minutes of SHSe ($r=0.18$), size, and ventilation properties of exposure location ($r=0.24$ and 0.25 , respectively), and total number of SHSe ($r=0.23$).⁴⁷ O'Connor *et al* investigated SHSe in pregnant women by asking if they had SHSe for at least 1 h during the week they were monitored; the investigators found poor agreement with urine cotinine concentration ($\kappa=0.08$).³⁵

Of the 18 studies validating parents' report of SHSe in children using urine cotinine, exposure measurements were highly correlated with questions that were more specific and captured exposure intensity (supplementary table S6). Poor agreement was reported for children's SHSe in the home ($\kappa=0.33$), in the same room as a smoker ($\kappa=0.11$) and SHSe within the past 2 days ($\kappa=0.05-0.11$).^{48–49} Willers *et al*, using an intensity scale based upon household members' smoking status, found strong a correlation with urine cotinine ($r=0.61$).⁵⁰ Another study collecting information on the number of cigarettes smoked inside the house, as well as number of household smokers, also showed a strong correlation ($r\geq 0.59$).⁴² CPD and number of smokers in the household had moderate to strong correlations with cotinine measurements in several studies.^{15–34–42–51–53} A study validated questions using infant's NNAL (4-[methylnitrosamino]-1-[3-pyridyl]-1-butanol) levels in urine.⁵⁴ The correlation between cigarettes smoked, in the home and car, and NNAL concentrations was low.

Other methods of validation of SHSe questions include using cotinine in saliva, blood, plasma or serum (supplementary table S7). Studies validating adult's reported SHSe questions

Table 3 Recommended questions for studies assessing secondhand smoke exposure (SHSe)

Question	Location	Source	Reliable*	Validation air*	Validation biomarker*
Lifetime					
Number of years living with a smoker	Home	Mother	Yes		
Adulthood					
Living with a regular smoker (yes/no)	Home	Wife	Yes		
		Husband	Yes		
		Mother	Yes		
No. of years sharing the home with smoker(s)	Home	Spouse	Yes		
		Other HM	Yes		
		Parents	Yes		
No. of pack-years of SHSe (number of cigarette packs smoked per day by the source × number of years the source has smoked)	Total	All HM	Yes		
No. of cigarettes smoked	Home	All smokers		Nicotine/ particulate matter	
	Work	All smokers		Nicotine	
No. of smokers	Work	All smokers		Nicotine/ particulate matter	Saliva cotinine
	Work	All smokers		Nicotine/ particulate matter	Urine cotinine
No. of hours of SHSe	Work	All smokers		Nicotine	
No. of hours of exposure × no. of smokers × proximity to the participant	Total	All smokers		Nicotine	
Childhood (past)					
SHSe during childhood (yes/no)	Total	Mother	Yes		
		Father	Yes		
SHSe while mother was pregnant (yes/no)	Total	Mother	Yes		
No. of years sharing the home with smoker(s)	Home	Mother	Yes		
		Father	Yes		
		Other HM	Yes		
No. of hours per day of SHSe	Total	Father	Yes		
		Other HM	Yes		
No. of pack-years of SHSe	Total	Parents	Yes		
		All HM	Yes		
Pregnant women (third trimester)					
Hours of woman's SHSe at home	Home	All HM			Cord blood cotinine
Cigarettes per day smoked in their presence	Home	All HM			Cord blood cotinine
	Home or work	All HM and coworkers			Cord blood cotinine
Childhood (current)					
Smoking status of parent	Total	Mother			Saliva cotinine
		Father			Saliva cotinine
Hours of child's SHSe at home	Home	All smokers		Nicotine†	
Cigarettes per day smoked	Total	Mother	Yes		Plasma cotinine
		All HM			Plasma cotinine
Cigarettes per day smoked in the home	Home	Mother	Yes		Urine cotinine
		Parents	Yes		Urine cotinine/ hair nicotine
		All HM			Urine cotinine
		All HM and visitors			Urine cotinine
		All smokers			Hair nicotine
Cigarettes per day smoked in the presence of the child	Home	All smokers	Yes		Urine cotinine†
	Total	All smokers			Hair nicotine
No. of cigarettes smoked	Total	Mother		Nicotine	
No. of cigarettes smoked in the home	Home	All smokers		Nicotine	Urine cotinine
		Mother			Urine cotinine
No. of cigarettes smoked in the presence of the child	Total	Mother		Nicotine	
		All smokers	Yes		Urine cotinine
		Mother		Nicotine	Urine cotinine
		Parents	Yes		Urine cotinine
		Mother	Yes		Urine cotinine
Weekly no. of cigarettes smoked	Car	Mother	Yes		
	Total	Mother			Urine cotinine
		Mother	Yes	Nicotine	
		Father	Yes		
	Home	Parents	Yes		

Continued

Table 3 Continued

Question	Location	Source	Reliable*	Validation air*	Validation biomarker*
Weekly no. of cigarettes smoked in the home in the presence of the child	Home	Mother	Yes		
		Father	Yes		
		Parents	Yes		
		All smokers	Yes		
Weekly no. of cigarettes smoked in the presence of the child No. of smokers	Total	All smokers	Yes		
	Total	All HM			Hair nicotine/ urine cotinine/ serum cotinine
Cigarette butt counts in 24 h Cigarette butt counts × hours spent in living room	Home	Mother			Urine cotinine
	Home	Father			Urine cotinine

* $\kappa \geq 0.75$ or correlation coefficient (r) ≥ 0.50 .

†Reported by the smoking parent.

H, hair nicotine; HM, household members.

with saliva cotinine concentrations found moderate correlations with questions about total hours ($r=0.34-0.45$) or minutes ($r=0.36$) of SHSe.^{37 55 56} However, daily SHSe poorly agreed ($\kappa \leq 0.15$) with saliva cotinine.⁵⁵ Validation studies of children's SHSe showed intermediate to strong correlations saliva cotinine levels with dichotomous reports of smoking in the home ($\kappa=0.44-0.47$), and maternal and paternal smoking status ($r=0.51-0.56$).¹³ Paternal, maternal and total CPD were moderately to strongly correlated with children's plasma cotinine levels ($r=0.40-0.59$).¹⁵ Data from NHANES III obtained from 2516 children aged 4–16 years showed a strong correlation ($r=0.57-0.73$) between number of household smokers and serum cotinine.¹⁴ A study among pregnant women in their third trimester found strong correlations of cord blood cotinine levels with SHSe duration ($r=0.52$) and CPD exposed ($r=0.52$).⁵⁷

CONCLUSIONS

Research on the health effects of SHSe has been conducted for over three decades, and exposure surveillance has been in place for over 20 years in the USA.^{58 59} A variety of instruments, although limited in their accuracy, have been developed and applied; they have proven useful for conducting aetiological studies and tracking SHSe of populations. Extensive experience with questionnaires allows us to (1) offer recommendations about use of instruments in various contexts; and (2) point to research needs. In table 3, we present questions that meet reasonable standards for reliability and validity.

Researchers can assess SHSe with some confidence as study participants will answer reliably about childhood exposure to SHS by their mother (including if their mother smoked during pregnancy) or their father, and during adulthood if they live with a regular smoker. Accurate questions are still needed for adults living with their adult children, other relatives and non-relatives that smoke. Study participants can consistently report the number of years of SHSe during their lifetime (source: mother), childhood (source: mother, father, or others) and adulthood (source: spouse or other household members). Hours per day of exposure during childhood (source: father or others) as well as pack-years of exposure (source: parents and all household members) and during adulthood (source: all household members and spouse) were also shown to be reliable questions.

For children's current exposure, researchers can obtain reliable answers when asking adults, and sometimes older children, about the amount of CPD the mother or their parents smoke, either overall or in the child's presence, as well as the number of

cigarettes smoked by the mother, parents, or all smokers in the child's presence at home, outside of the home, or in a car. Research is needed to answer questions on current SHSe in children and adolescents, and to assess the reliability of responses from parents, older children and adolescents answering questions regarding SHSe (yes/no) and whether they live with a smoker, intensity of exposure and duration of exposure.

Assessments of exposure at home, in transport and in social settings are untested for reliability or validity. As more communities implement smoke-free legislation, the social norm for smoking inside the home or car will shift to formal smoking restrictions or bans.^{45 60} We encourage researchers to test these questions (table 3) in their studies to continue building a set of core questions for SHSe assessment. For example, FAMRI CoE investigators are determining the accuracy of a set core of questions, available for investigators at the FAMRI American Academy of Pediatrics Richmond Center of Excellence's website, for the assessment of children's SHSe.

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ASSESSING SECONDHAND SMOKE EXPOSURE WITH REPORTED MEASURES

SUPPLEMENTARY TABLES

Supplementary Table S1. Validation of questions about exposure to secondhand smoke using nicotine in the air and respirable suspended particulates at home

Reference Population	Validation Method	SHSe Question	Values
SHSe status (Yes/No)			
Air Nicotine			
O'Connor et al. 1995 [1] 254 NSMK pregnant women	Air nicotine (passive personal monitor) 1-week sampling period exposed ($>0.01 \mu\text{g}/\text{m}^3$)	SHSe status† “Exposed to someone else’s smoking for at least one hour during the monitoring week”	$\kappa = 0.29$ Sens = 51.9; Spec. = 77.0 PPV = 70.8; 36.0% miss.
Gehring et al. 2006 [2] Multi-country study presenting validation results by site. Homes with children in: Germany (aged 3-7 years) Netherlands (aged 4-6 years) Sweden (aged 5-9 years)	Air nicotine (passive monitor)† 2-week sampling period exposed ($\geq 0.24 \mu\text{g}/\text{m}^3$)	Smoking in the living room Any questionnaire reported smoking during measurement period	Germany (N=347) Sens=61.4; Spec=95.7 PPV=67.5; NPV=94.5 Netherlands (N=335) Sens=77.8; Spec=80.6 PPV=32.6; NPV=96.8 Sweden (N=354) Sens=0.00; Spec=96.8 PPV=0.00; NPV=97.4
Gehring et al. 2006 [2] Multi-country study presenting validation results by site. Homes with children in: Germany (aged 3-7 years) Netherlands (aged 4-6 years) Sweden (aged 5-9 years)	Air nicotine (passive monitor)† 2-week sampling period exposed ($\geq 0.24 \mu\text{g}/\text{m}^3$)	Smoking in the living room Daily questionnaire reported smoking during measurement period	Germany (N=347) Sens=55.3; Spec=98.0 PPV=77.8; NPV=94.5 Netherlands (N=335) Sens=73.3; Spec=95.6 PPV=66.7; NPV=96.8
		Smoking in the living room Any questionnaire reported smoking at child’s age 4 years (cohort data)	Germany (N=347) Sens=66.5; Spec=87.2 PPV=42.9; NPV=95.0 Netherlands (N=335) Sens=66.7; Spec=91.0 PPV=45.8; NPV=96.0 Sweden (N=354) Sens=55.6; Spec=81.2 PPV=7.20; NPV=98.6
Intensity of Exposure			
Air Nicotine			
Berman et al. 2003 [3] 123 households with children with asthma age 2-14 years	Air nicotine (passive monitor) 2 consecutive 1-week sampling periods	CPD smoked in the home	$r=0.36^*$
Leaderer et al. 1991 [4] 96 homes	Air nicotine (passive monitor) Main living area 1-week sampling period	No. of cigarettes smoked Diary	All samples: $r=0.82$ Samples with detectable nicotine (N=47): $r=0.74$
Marbury et al. 1993 [5] 48 families including 25 smoking families	Air nicotine (passive monitor) Activity room 1-week sampling period	No. of cigarettes smoked in the home	Activity room: All families: $r=0.86$ Smoking families: $r=0.77$ Bedroom: All families: $r=0.80$ Smoking families: $r=0.77$

Reference Population	Validation Method	SHSe Question	Values
Emerson et al. 1995 [6] 91 families with an asthmatic child 6-17 years old	Air nicotine (passive monitor) 2-week sampling period at baseline, 2-month and 6-month follow-up	No. of cigarettes smoked in the home Diary (2-week period)	Per week: $r=0.24-0.35^{**}$ Workday: $r=0.25-0.39^{**}$ Nonworkday: $r=0.19-0.29^{**}$
		No. of cigarettes smoked in the room where the filter was installed Diary	$r=0.25-0.41^{**}$
Zakarian et al. 2004 [7] 24 mothers with children aged ≤ 4 years recruited in a randomized controlled trial	Air nicotine (active monitor) 1-week sampling period	No. of cigarettes smoked inside the home per week by all smokers	Intervention $r=0.69$ Control $r=0.88^{**}$
O'Connor et al. 1995[1] 254 NSMK pregnant women	Air nicotine (passive personal monitor) 1-week sampling period	No. of cigarettes	At home: $r=0.34^{***}$ At work: $r=0.17^{**}$
		No. of smokers	At home: $r=0.35^{***}$ At work: $r=0.16^*$
Particulate Matter			
Leaderer et al. 1991 [4] 96 homes	RSP sampling	No. of cigarettes Diary	All samples $r=0.74$ Samples with detectable nicotine $r=0.63(N=47)$
Duration of Exposure			
Air Nicotine			
O'Connor et al. 1995 [1] 254 non-smoking pregnant women	Air nicotine (passive personal monitor) 1-week sampling period	Minutes of SHSe	All locations: $r=0.41^{***}$ At home: $r=0.34^{***}$ At work: $r=0.18^{**}$ In social settings: $r=0.28^{***}$
Berman et al. 2003 [3] 68 children with asthma age 2-14 years	Air nicotine (passive monitor) 2 consecutive 1-week sampling periods	Hours per week when someone in the household is smoking	$r=0.49^*$
Eisner et al. 2006 [8] 77 non-smoking adults with COPD	Air nicotine (passive personal monitor) 1-week sampling period	Hours of SHSe (Categorized: None, Lower (1-3 hours/week), Higher (≥ 4 hours/week))	$r=0.06$

Abbreviations: SHSe=secondhand smoke exposure; NSMK= Nonsmoking; κ =kappa; Sens=sensitivity; Spec=specificity; PPV=positive predictive value; NPV=negative predictive value; miss=misclassified; r =correlation coefficient; CPD: cigarettes per day; RSP=respiratory suspended particles; COPD= Chronic Obstructive Pulmonary Disease; †gold standard; * $p<0.05$; ** $p<0.01$; *** $p<0.001$.

Supplementary Table S2. Validation of questions about exposure to secondhand smoke using nicotine in the air and respirable suspended particulates at work

Reference Population	Validation Method	SHSe Question	Values
Intensity of Exposure			
<i>Air Nicotine</i>			
Thompson et al. 1989 [9] 36 restaurants	Air nicotine (active personal monitor) At least 1 hour	No. of cigarettes during sampling air time	r=0.78***
		No. of smokers	r=0.67***
Coultas et al. 1990 [10] 15 NSMK adults	Air nicotine (active personal monitor) 1 work shift sampling	No. of smokers	r=0.62*
Bolte et al. 2008 [11] 28 restaurants	Air nicotine (active monitor) 4 hours during main visiting hours	No. of smokers	r=0.61**
<i>Particulate Matter</i>			
Bolte et al. 2008 [11] 28 restaurants	RSP sampling 4 hours during main visiting hours Gravimetry or Spectrometry	No. of smokers	r=0.5*
Duration of Exposure			
<i>Air Nicotine</i>			
Coultas et al. 1990[10] 15 NSMK adults	Air nicotine (active personal monitor) 1 work shift sampling	Hours of exposure at work	r=0.54*
<i>Particulate Matter</i>			
Coultas et al. 1990 [10] 15 NSMK adults	RSP sampling	Hours of exposure at work	r= 0.53*

Abbreviations: SHSe=secondhand smoke exposure; NSMK= Nonsmoking; r=correlation coefficient; RSP=respiratory suspended particles; *p<0.05; **p<0.01; ***p<0.001.

Supplementary Table S3. Validation questions about exposure to secondhand smoke using nicotine in the air and respirable suspended particulates among children

Reference Population	Validation Method	SHSe Question	Values
Intensity of Exposure			
Emerson et al. 1995 [6] 91 families with an asthmatic child 6-17 years old	Air nicotine (passive monitor) 2-week sampling period at baseline, 2-month and 6-month follow-up	No. of cigarettes to which the child is exposed at home from parent Diary (2-week period)	Per week: $r=0.13-0.26^*$ Workday: $r=0.15-0.25^{**}$ Nonworkday: $r=0.07-0.23^{**}$
		No. of cigarettes to which the child is exposed at home from all smokers	Per week: $r=0.22-.35^{**}$
		No. of cigarettes to which the child is exposed in the room where the filter was installed Diary	$r=0.27-0.30^{**}$
		CPD to which the child is exposed in the entire home Diary	$r=0.23-0.31^{**}$
		Average CPD to which the child is exposed at home Diary	$r=0.27-0.43^{**}$
		Zakarian et al. 2004 [7] 24 mothers with children aged ≤ 4 years recruited in a randomized controlled trial	Air nicotine (active monitor) 1-week sampling period
No. of cigarettes to which the child was exposed from the mother	Intervention $r=0.66$ Control $r=0.83^*$		
No. of cigarettes to which the child was exposed at home from the mother	Intervention $r=0.50$ Control $r=0.64^*$		
No. of cigarettes smoked inside the home per week by the mother	Intervention $r=0.65$ Control $r=0.84^*$		
Wong et al. 2004 [12] 130 children with asthma age 2-14 years	Air nicotine (passive monitor) 2-week sampling period	Hours of smoking indoors at home	Child's report (age >7 years) $r=0.42^{**}$ Parents' report $r=0.56^{**}$
Duration of Exposure			
Berman et al. 2003 [3] 48 children with asthma age 2-14 years	Air nicotine (passive monitor) 2 consecutive 1-week sampling periods	Hours per week that the child is exposed to SHS in the home	$r=0.36^*$
Wong et al. 2004 [12] 125 children with asthma age 2-14 years	Air nicotine (passive monitor) 2-week sampling period	Hours of SHSe of child at home indoors	Child's report (age >7 years) $r=0.25^{**}$ Parents' report $r=0.36^{**}$

SHSe=secondhand smoke exposure; r =correlation coefficient; CPD= cigarettes per day; * $p<0.05$; ** $p<0.01$; *** $p<0.001$.

Supplementary Table S4. Validation questions on indices of exposure to secondhand smoke using nicotine in the air

Reference Population	Validation Method	SHSe Question	Values
Index of Exposure			
<i>Air Nicotine</i>			
Coghlin et al. 1989 [13] 19 non-smoking adults age 25-54 years	Air nicotine (passive personal monitor) 1-week sampling period	Indices of SHSe 7-day Diary	h: r=0.84
			hs: r=0.79
			hsp: r=0.91
			hspi(3-point scale): r=0.890
			see reference for other indexes
			Indices of SHSe
			h: r=0.82
			hs: r=0.87
			hsp: r=0.95
			hspi(3-point scale): r=0.88
see reference for other indexes			
Indices of SHSe Refined hsp (hsp*)= (hsp)/ hsi(5,10 scale)	Among subjects with high levels of social exposure (N=33)	hsp: r=0.631 hsp*: r=0.890	
	Among all subjects: hsp*: r=0.980		
	see reference for other indexes		

Abbreviations: SHSe=secondhand smoke exposure; r=correlation coefficient; h=hours; s=no. of smokers; p= proximity; i=intensity (e.g. hs: hours*smokers); * p<0.05;** p<0.01; ***p<0.001.

Supplementary Table S5. Validation questions about exposure to secondhand smoke among children using nicotine in the hair

Reference Population	SHSe Question	Exposure Source	Values
Intensity of Exposure			
Nafstad et al. 1995 [14] 72 children 1-3 yrs old	CPD to which the child is exposed		r=0.64***
Al-Delaimy et al. 2000 [15] 112 children 3 mo.- 10 yrs old vs. 76 SMK or NSMK mothers	No. of smokers	None 1 smoker 2 smokers >2 smokers	<0.1 ng/mg 0.28 1.46 2.02 ***
Al-Delaimy et al. 2002 [16] 297 children 3–27 months old	No. of smokers		0.69***
Al-Delaimy et al. 2000 [15] 112 children 3 mo.- 10 yrs old vs. 76 SMK or NSMK mothers	CPD smoked in the house	Among smoking households, there was an increase in hair nicotine levels per CPD smoked by:	
		Total	4.5%**
		Mother	10.5%***
		Father	4.0%*
		All other adults	5.0%*
Al-Delaimy et al. 2002 [16] 297 children 3–27 months old	CPD smoked inside the house	Total	r=0.7
		Parents	r=0.68
Woodruff et al. 2003 [17] 134 children 1-9 yrs old	No. of cigarettes smoked in the presence of the child in the past month		r=0.23** r=0.22* ^a
Wipfli et al. 2008 [18]	No. of smokers	Total	None 1.0 ^b 1 smoker 2.3 (1.8, 2.8) ≥2 smokers 3.8 (3.0, 4.9)
	CPD		<10 1.0 ^b 10-19 1.5 (1.2, 1.9) ≥20 1.5 (1.2, 1.9)
	Policy restricting smoking in the home		Yes 1.0 ^b No 2.6 (2.0, 3.3)
	Smokers sharing child's bedroom		None 1.0 ^b 1 2.1 (1.6, 2.5) 2 3.4 (2.3, 5.0) 3 4.7 (1.5, 14.2)
	Mother also smokes		No 1.0 ^b Yes 2.9 (2.1, 4.0)
	Mother's CPD		<10 1.0 ^b 10-19 2.6 (1.6, 4.4) ≥20 3.7 (2.3, 6.1)

Abbreviations: SHSe=secondhand smoke exposure; SMK: Smoker; NSMK: Nonsmoking; CPD: cigarettes per day. r=correlation coefficients; * p<0.05;** p<0.01; ***p<0.001. ^a hair cotinine; ^bGeometric Mean Ratio.

Supplementary Table S6. Validation of questions about exposure to secondhand smoke using cotinine in urine among adults and children

Reference Population	Validation Method of Biomarker	Exposure Source	Values
Adults			
SHSe status (Yes/No)			
Question details			
O'Connor et al. 1995 [1] 282 NSMK pregnant women	ng cotinine per mL exposed (>2 ng/mL)	All sources	$\kappa = 0.08$; Sens. = 56.0; Spec. = 51.8 PPV = 53.7; 46.1% miss.
SHSe status (Yes/No): "Exposed to someone else's smoking for at least one hour during the monitoring week"			
Duration of exposure			
Coultas et al. 1989 [19] 145 NSMK adults	ng cotinine per mg creatinine	All sources	$r=0.29-0.32$
No. of hours of SHSe 24 hours before			
Cummings et al. 1990 [20] 663 NSMK and ex-smokers adults	ng cotinine per mL	All sources	0.18* Adjusted for number of exposures to SHS
No. of minutes of SHSe in the previous 4 days			
Intensity of exposure			
Cummings et al. 1990 [20] 663 NSMK and ex-smokers adults	ng cotinine per mL	All sources	0.19* Adjusted for number of exposures to SHS:
Number of smokers			
SHSe at work			
Coultas et al. 1990 [10] 14 NSMK adults	ng cotinine per mg creatinine	All sources at work	Hours of exposure at work $r=0.57^*$
Hours of exposure at work			Number of smokers during a work shift
Total number of smokers during a work shift			$r=0.39$
Children			
SHSe status (Yes/No)			
Question details			
Seifert et al. 2002 [21] 50 children 8.5 mo-9.5 yrs old	ng cotinine per mg creatinine exposed (>30ng/mg)	Parents	76% [†]
		Parents and others	80% [†]
SHSe status (Yes/No)			
Wong et al. 2002 [22] 145 children aged ≥ 7 yrs	ng cotinine per mL	Mother	$r=0.38$
SHSe status (Yes/No)			

Reference Population	Validation Method of Biomarker	Exposure Source	Values
Callais et al. 2003 [23] 310 children	CCR	Father Parents	r=0.35 k=0.08
SHSe status (Yes/No) within 2 days			with asthma N=154 k=0.11 without asthma N=156 k=0.054
Johansson et al. 2005 [24] 153 smoking parents of children aged 2.5 to 3 years	ng cotinine per mL exposed (>6 ng/mL)	Parents	Sens.=0.3;Spec.=0.9;ROC=0.69
SHSe status (Yes/No) Non SHSe: parents smoking outside with door closed	ng cotinine per mL exposed (>3 ng/mL)	Parents	Sens.=0.6;Spec.=0.7
Boyaci et al. 2006 [25] 188 children aged 6-11 years	ng cotinine per mL exposed (>10 ng/mL)	All sources	Home κ = 0.33***;Sens. =70;Spec. =71
SHSe status (Yes/No) in the home		All sources	Same room κ = 0.11***;Sens. =38.9;Spec. =79.5
SHSe status (Yes/No) in the same room			
Gehring et al. 2006 [2] 347 homes with children aged from 3 to 7 years	ng cotinine per mL exposed (>2 ng/mL)	All sources	24 hrs before urine sampling Sens=46.2;Spec=97.6 PPV=75.0;NPV=92.2
SHSe status (Yes/No) 24 hours before urine sampling			Daily questionnaire Sens =42.3;Spec =93.0 PPV =47.8;NPV =91.4
SHSe status (Yes/No) Daily questionnaire reporting smoking			Daily questionnaire at 4 years old Sens =52.2;Spec =89.5 PPV =49.0;NPV =90.7
SHSe status (Yes/No) Any questionnaire reported smoking at child's age 4 years			
Ekerbicer et al. 2007 [26] 347 children aged 9-11 yrs	ng cotinine per mL exposed (>10 ng/mL)	Parents and others <i>Children's self-report</i>	Sens= 89% Spec =92%
SHSe status (Yes/No)			
Intensity of exposure			
Question details			
Willers et al. 2000 [27] 104 children aged 8-13 years with asthma	µg cotinine per g creatinine	Parents and others	r=0.76***
CPD smoked in the home		Mother	r=0.74***
		Father	N=102 r=0.41**
Al-Delaimy et al 2002 [16] 158 children 3–27 months old	ng cotinine per mg creatinine	Parents	r=0.67***
CPD smoked inside the home		Household members	r=0.61
		Household members and visitors	r=0.59
Wong et al. 2002 [22] 146 children aged ≥7	ng cotinine per mL	Parents and others	r=0.41
CPD smoked in the home			
Berman et al. 2003 [3] 137 households with children with asthma age 2-14 years	ng cotinine per mL	Parents and others	r=0.44*
CPD smoked in the home			

Reference Population	Validation Method of Biomarker	Exposure Source	Values
Tyc et al. 2009 [28] 124 parents of a child with cancer aged <18 years In parenthesis is listed which parent reported the exposure	ng cotinine per mL	All parents (all sources)	r=0.48**
		All parents (SMK parent)	N=123 r=0.34**
		SMK parent (Self)	N=90 r=0.35***
		SMK parent (all sources)	N=90 r=0.54***
		NSMK parent (SMK parent)	N=33 r=0.16
		NSMK parent (all sources)	N=34 r=0.38*
3-Day Average CPD to which the child is exposed in the entire home ("How many cigarettes did you smoke in your home and to how many was your child exposed?")			
Marbury et al. 1993 [5] 48 children age under 2 years 25 smoking families	ng cotinine per mg creatinine	All sources	r=0.80 Smoking families: r=0.74
No. of cigarettes smoked in the home			
Callais et al. 2003 [23] 310 children 154 children with asthma 156 children without asthma	CCR	Parents	r=0.22*** with asthma r=0.27*** without asthma r=0.17*
Cigarette equivalents smoked at home 2 days prior to collection.			
Hovell et al. 2002 [29] 204 children with asthma 3-17 years old	ng cotinine per mL	All smokers	r=0.34-0.47***
No. of cigarettes smoked while the child was in the same room or car in the past 7 days			
Zakarian et al. 2004 [7] 64 mothers with children aged ≤4 years recruited in a randomized controlled trial. Baseline, 3-, 6-, and 12-month follow-up.	ng cotinine per mL	Mother	At home r=0.42-0.59**
		All sources	At home, in the car, and elsewhere r=0.43-0.67**
		Mother	Inside the home r=0.40-0.63**
		All smokers	Inside the home r=0.45-0.65***
No. of cigarettes to which the child was exposed: 1) at home; 2) at home, in the car, and elsewhere, or 3) inside the home			
No. of cigarettes smoked per week		Mother	Cigarettes smoked per week r=0.25-0.53**
Jurado et al. 2004 [30] 115 parents of children aged 3 to 6 years	ng cotinine per mg creatinine	Parents	r=0.31***
No. of smoking parents			
Al-Delaimy et al 2002 [16] 158 children 3–27 months old	ng cotinine per mg creatinine	Household members	r=0.59***
		Household members and visitors	r=0.61
No. of smokers			
Wong et al. 2002 [22] 144 children aged ≥7 yrs	ng cotinine per mL	Parents and others	r=0.12

Reference Population	Validation Method of Biomarker	Exposure Source	Values
Number of smokers			
Chan et al. 1995 [31] 4 families (1 NSMK 3 SMK) 9 children aged 5-14 yrs	Day-averaged CCR (ng/mg)	Father	in the living room N=52 r=0.77 in the living room in a week N=48 r=0.77
Stepans et al. 1999 [32] 15 newborns	ng cotinine per mg creatinine	Mother	At 2 weeks r=0.71** At 4 weeks (N=14) r=-0.14 At 6 weeks (N=14) r= 0.61
No. of butts collected during 24 hours			
Exposure Scores			
Question details			
Stepans et al. 1999 [32] 15 newborn babies	ng cotinine per mg creatinine		At 2 weeks r=0.09 At 4 weeks r=-0.44 At 6 weeks r=-0.02
Composite score of SHSe			
Seifert et al. 2002 [21] Parents of 50 children aged 8.5 months to 9.5 years	ng cotinine per mg creatinine	Both parents and another source at least once a week	r=0.62***
SHSe intensity score: from 0=no exposure to 5=highest rank of exposure			
Willers et al. 2004 [33] 23 children aged 1-13 years	nmol cotinine per mg creatinine	Parents and others	r=0.61**
SHSe Intensity[‡]			

Abbreviations: SHSe=secondhand smoke exposure; SHS: Secondhand smoke; † Percent agreement; NSMK: Nonsmoking; r: correlation coefficient; κ: kappa; Sens: sensitivity; Spec: specificity; PPV :positive predictive value; NPV: negative predictive value; CPD: cigarettes per day; miss: misclassified; CCR: Cotinine Creatinine ratio; SMK: smoking; *p<0.05; ** p<0.01; ***p<0.001. † 0=none of the family members smokes or has smoked since their child's birth; 1=none smokes indoors or had quit smoking since 6 months; 2=only father smokes indoors at home; 3=only mother smokes indoors at home; 4= two family members or more smoke indoors at home.

Supplementary Table S7. Validation of questions about exposure to secondhand smoke among adults and children using cotinine in saliva, serum, plasma, or blood.

Reference Population Question details	Validation Method of Biomarker	Exposure Source	Values
Adults			
Chen et al. 2002 [34] 1153 NSMK adults	ng cotinine per mL serum	All sources	$\kappa = 0.13-0.15^{**}$
Daily SHSe status	exposed (>0.0 ng/mL)		
Emmons et al 1994 [35] 184 NSMK adults	ng cotinine per mL saliva	All sources	$r=0.36^{***}$
No. of minutes of SHSe			
Chen et al. 2002 [34] 1153 NSMK adults	ng cotinine per mL serum	All sources	$r=0.34-0.35^{***}$
Daily hours of SHSe	exposed (>0.0 ng/mL)		
SHSe at work			
Coultas et al. 1990 [10] 11 NSMK adults	ng cotinine per mL saliva	All sources at work	Hours of SHSe $r=0.45$
Hours of SHSe at work		All sources at work	Number of smokers $r=0.63^*$
No. of smokers during a work shift			
Children			
SHSe status (Yes/No)			
Jarvis et al. 1985 [36] 2594 children	ng cotinine per mL saliva	Mother	$r=0.56$
		Father	$r=0.51$
Smoking status of parent			
Lee et al 2005 [37] 341 children age 13-17 years 304 parents	ng cotinine per mL exposed (>0.10 ng/mL) saliva	Parents <i>Children's self-report</i>	$\kappa = 0.44 [0.31-0.56]$ Sens. = 46; Spec. = 93 PPV = 63; NPV = 87
SHSe status		Parents <i>Parents' report</i>	$\kappa = 0.44 [0.29-0.59]$ Sens. = 69; Spec. = 90 PPV = 39; NPV = 97
		Parents <i>Both report</i>	$\kappa = 0.47 [0.32-0.62]$ Sens. = 85; Spec. = 90 PPV = 37 NPV = 99
Duration of exposure			
Jedrychowski et al 2008 [38] 467 NSMK pregnant women (third trimester) 18-35 years of age	μg cotinine per mL cord blood	Household members	$r= 0.52$
Hours of SHSe at home			
Intensity of exposure			
Willers et al. 2000 [27] 72 children aged 8-13 years with asthma	μg cotinine per L plasma	Parents and others	$r=0.59^{***}$
CPD		Mother	$r=0.59^{***}$
		Father	$r=0.40^{**}$
Wilkinson et al 2006 [39] 2,516 participants aged 4-16 years (NHANES III). Results available by gender, race, education, poverty, region, and urban/rural.	μg cotinine per mL serum	Parents and others	$\kappa = 0.54 [0.51-0.57]$ Sens. =65 Spec. = 92
Any household smoker ("Does anyone who lives here smoke cigarettes in the home?")		Parents and others	$r= 0.67$
No. of household smokers			
Jedrychowski et al 2008 [38] 467 NSMK pregnant women (third trimester) 18-35 years of age	μg cotinine per mL cord blood	Household members	$r= 0.52$
CPD smoked in their presence: 1) at home or 2) at home or work		Household members and co-workers	$r= 0.54$

Abbreviations: SHSe=secondhand smoke exposure; SHS: Secondhand smoke; NSMK= Nonsmoking; r=correlation coefficient; κ =kappa; Sens=sensitivity; Spec=specificity; PPV=positive predictive value; miss=misclassified; CCR=Cotinine Creatinine ratio; * $p<0.05$; ** $p<0.01$; *** $p<0.001$. †Percent agreement; NPV: negative predictive value; CPD: cigarettes per day; miss=misclassified;

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