Third-hand tobacco smoke exposure and implications for public health

A background paper

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Characteristics and occurrence of third-hand tobacco smoke

The negative health effects of smoking and second-hand smoke (SHS) are well established, however, the concept of third-hand tobacco smoke (THS) is an emerging area of interest in public health (Acuff, Fristoe, Hamblen, Smith, & Chen, 2015; Burton, 2011). While, in contrast to active smoking and SHS, THS is invisible, it also leads to involuntary exposure to tobacco smoke products. This background paper provides a brief summary of current evidence relating to THS exposure and its implications for public health.

Characteristics of THS

THS has been described as ‘‘residual tobacco smoke pollutants that remain on surfaces and in dust after tobacco has been smoked, are re-emitted into the gas phase, or react with oxidants and other compounds in the environment to yield secondary pollutants” (Matt et al., 2011a, p. 1219). Dust, air, and surfaces of indoor environments (including floors, walls, furniture, bench tops and car dashboards) have been found to contain tobacco-related compounds such as nicotine, polycyclic aromatic hydrocarbons (PAHs), volatile N-nitrosamines, and tobacco-specific nitrosamines (TSNAs) (Bush & Goniewicz, 2015; Fortmann et al., 2010; Hoh et al., 2012; Hood, Ferketich, Klein, Pirie, & Wewers, 2014; Kim, Aung, Berkeley, Diette, & Breysse, 2008; Matt et al., 2011a; Matt et al., 2014; Matt et al., 2004; Matt et al., 2008; Matt et al., 2011b; Northrup, Matt, Hovell, Khan, & Stotts, 2015b; Ramirez et al., 2014; Schick et al., 2014; Thomas et al., 2014). Substances such as TSNAs, cotinine and formaldehyde are formed when nicotine reacts with ambient gases present in the indoor environment (including ozone and nitrous acid) (Destaillats, Singer, Lee, & Gundel, 2006; Petrick, Destaillats, Zouev, Sabach, & Dubowski, 2010; Petrick, Svidovsky, & Dubowski, 2011; Sleiman et al., 2010).

Occurrence of THS residues in the indoor environment

The majority of the compounds that are released into the air during smoking indoors deposit on room surfaces (Schick et al., 2014), and nicotine and other THS compounds are also absorbed by fabric (Bahl, Jacob, Havel, Schick, & Talbot, 2014; Bahl et al., 2015; Petrick et al., 2010; Schick et al., 2014; Ueta, Saito, Teraoka, Miura, & Jinno, 2010), carpet (Bahl et al., 2015; Van Loy, Riley, Daisey, & Nazaroff, 2001), and painted wallboard (Petrick et al., 2010; Van Loy et al., 2001). THS residues that are deposited on surfaces can be resuspended back into the air over time, providing a lingering source of tobacco-related compounds (Becquemin et al., 2010; Petrick et al., 2010; Singer, Hodgson, Guevarra, Hawley, & Nazaroff, 2002; Singer, Hodgson, & Nazaroff, 2003). THS release from, or through, surfaces (desorption) is affected by the relative humidity and air exchange rate of the indoor environment, and varies by surface type (Petrick et al., 2010).

THS compounds (such as nicotine, PAHs, and TSNAs) in dust are present in significantly higher concentrations in the homes of smokers than in the homes of non-smokers (Bush & Goniewicz, 2015; Hoh et al., 2012; Hood et al., 2014; Kim et al., 2008; Matt et al., 2011b; Northrup et al., 2015b; Ramirez et al., 2014; Thomas et al., 2014). The level of nicotine in household dust is correlated with the number of cigarettes smoked both inside (Hood et al., 2014; Kim et al., 2008; Northrup et al., 2015b; Ramirez et al., 2014) and outside (Ramirez et al., 2014) the home. Similarly, a greater number of cigarettes smoked inside used cars has been found to be associated with higher levels of nicotine in car surface dust (Fortmann et al., 2010; Matt et al., 2008). Preliminary data from a small longitudinal study suggest that THS accumulates in homes over time (Northrup et al., 2015b).

THS residues are also found on the skin after smoking. For example, the PAH residue on smokers' hands is approximately three times higher than that of non-smokers (Fleming, Anderson, Amin, & Ashley, 2012). THS residues are also detectable on the skin of non-smokers who spend time in indoor environments exposed to THS. The level of nicotine on the fingers of non-smokers was significantly higher among those living in homes previously occupied by smokers compared to those living in homes previously occupied by non-smokers (Matt et al., 2011b). These higher levels were likely due to the presence of THS residues in the home, as finger nicotine levels among non-smokers living in homes formerly occupied by smokers were significantly correlated with dust and surface nicotine levels (Matt et al., 2011b). In addition, people staying in hotels which allowed smoking in some areas had higher levels of nicotine on their fingers than those staying in hotels with complete smoking bans (Matt et al., 2014).

Presence of THS residues in smoke-free indoor environments

Smoke-free policies in homes and cars do not appear to completely eliminate the presence of THS residues, however. Significant levels of THS compounds in dust in smokers' homes and cars have been recorded, even when smoking bans are in place (Matt et al., 2004; Matt et al., 2008; Northrup et al., 2015b). This indicates that THS compounds may enter indoor spaces though air exchange (e.g. open windows and doors, and ventilation systems) and on the clothing, hair and skin of smokers. Similarly, compared with hotels with complete smoking bans, surface and air nicotine was higher in non-smoking and smoking rooms and hallways of hotels in California that had partial smoking bans (i.e. allowed smoking in some areas) (Matt et al., 2014). A small study also found nicotine residues on the furniture and incubators/cribs in a neonatal intensive care unit where parents who were smokers visited their children (Northrup et al., 2015a).

THS also remains after smokers move out of their homes. Nicotine has been found to contaminate homes of non-smokers that were formerly occupied by smokers, exposing non-smokers to THS residues (Matt et al., 2011a; Matt et al., 2011b). THS has significant longevity, and some gas- and particle-phase THS compounds can remain in indoor environments for days to months after smoking has last taken place (Bahl et al., 2015; Destaillats et al., 2006; Giraldi, Fovi De Ruggiero, Marsella, & De Luca d'Alessandro, 2013; Matt et al., 2011a; Matt et al., 2004; Matt et al., 2008; Matt et al., 2011b; Singer et al., 2002; Singer, Revzan, Hotchi, Hodgson, & Brown, 2004). In a laboratory setting it was found that THS compounds in cotton and polyester fabrics still remained in significant quantities 19 months after the last exposure to tobacco smoke (Bahl et al., 2014).

Exposure to third-hand tobacco smoke

Routes of THS exposure

There are multiple potential exposure routes for THS compounds, as they can be present in dust, air, and on surfaces of indoor environments where smoking has previously occurred. THS exposure could occur through involuntary ingestion, dermal (skin) absorption, and inhalation (Acuff et al., 2015; Matt et al., 2011a), as evidenced by the presence of THS compound metabolites in the urine of exposed individuals. For example, it has been found that the higher the air and surface nicotine in a home, the higher the urinary cotinine (the metabolite of nicotine) of residents (Matt et al., 2011b; Northrup et al., 2015b). Similarly, those staying in hotels without complete smoking bans showed higher levels of finger nicotine and urine cotinine than those staying in hotels with complete smoking bans (Matt et al., 2014). When evaluating THS exposure, it is important to consider that the extent of intake will depend on a variety of factors, including the concentration of THS compounds (which will vary with the number of cigarettes smoked, the air exchange rate, and the time elapsed since smoking), the solubility of THS in saliva or sweat, and the variable composition of THS over time (Bahl et al., 2014).

Population groups most at risk of THS exposure

It is logical to assume that smokers and those sharing indoor environments with smokers will be exposed to THS to the greatest extent. However, non-smokers in smoke-free environments can also be exposed to THS, for example through dermal absorption when non-smokers occupy homes or vehicles previously inhabited by smokers, smoke infiltration, or smokers bringing THS residues inside (Acuff et al., 2015; Matt et al., 2011a).

Infants and young children may be particularly vulnerable to any THS-related risks because they exhibit age-specific behaviours that could increase their exposure (Acuff et al., 2015; Bahl et al., 2014; Ferrante et al., 2013; Matt et al., 2011a). They tend to spend more time indoors, crawl and play on the floor, mouth surfaces and objects (such as toys, upholstery, and furniture, that cannot be washed easily or often), and have frequent hand-to-mouth contact. It has been estimated that Infants who mouth cloth that has been exposed to tobacco smoke will be exposed to significant amounts of THS compounds, and exposure to nicotine and TSNAs from residual THS are above what toddlers (and adults) could receive by inhaling SHS (Bahl et al., 2014).

Some vulnerable populations may be disproportionately exposed to THS, such as those living in social housing (Winickoff et al., 2009). In New Zealand there are few smoke-free policies in place for social housing (Christchurch being one exception (CCC, 2015)), and THS residues accumulated over time have the potential to expose both current and future residents. THS exposure is also a concern for multi-unit dwellings because tobacco smoke can travel through ventilation systems and gaps in dwelling exteriors, contaminating other units, and exposing residents of non-smoking units to THS (Acuff et al., 2015; Matt et al., 2011a).

Health effects of exposure to third-hand tobacco smoke

The health effects of human exposure to THS residues have not been thoroughly studied to date. There are also several difficulties associated with investigating the health effects of THS exposure, including challenges quantifying exposure accurately, identifying suitable biomarkers, and differentiating THS exposure from SHS exposure. In addition, there is evidence that THS exposure involves different time profiles (i.e. a relatively low level of exposure over long periods of time), multiple compounds with varying concentrations in different media (air, surfaces and dust) and environmental conditions, and different exposure routes (inhalation, dermal contact and ingestion) (Ferrante et al., 2013). While robust evidence is not yet available to fully evaluate the potential health hazards of THS exposure, it is possible to consider potential effects on human health of some of the known THS compounds (Ferrante et al., 2013).

Epidemiological evidence

Some THS compounds, such as certain TSNAs and PAHs have been classified by the International Agency for Research on Cancer as carcinogens (Cogliano et al., 2004; IARC & WHO, 2007, 2010; Secretan et al., 2009; Straif et al., 2005). Ramirez and colleagues (2014) estimated the potential cancer risk through non-dietary ingestion and dermal exposure to carcinogen N-nitrosamines and TSNAs measured in house dust samples. Estimates of cancer risk were greater for those living in homes currently occupied by a smoker than those living in homes with no smokers. The median cancer risk estimation for those aged up to 70 years from the exposure to all nitrosamines measured in smoker-occupied homes was two excess cases per 10,000 population. For non-smoker-occupied homes, the median estimated risk was 0.7 excess cases per 10,000 population (Ramirez et al., 2014).

A large cross-sectional study with 31,584 South Korean children found that exposure to THS (defined as parental smoking, but not in the presence of their children) was significantly associated with a greater frequency of cough-related symptoms than for children from households with non-smoking parents (Jung, Ju, & Kang, 2012). The frequency of cough-related symptoms among children exposed to THS was significantly lower than among children exposed to SHS (defined as parental smoking in the presence of their children). Another recent study has estimated that 5–60 percent of the increased mortality risk associated with living with a smoker could be attributed to THS (Sleiman et al., 2014).

In vitro studies

There is some preliminary data from *in vitro* studies that THS compounds can induce negative effects on human cells. A study investigating the genotoxicity of both short-term (laboratory chamber exposed to smoke from five cigarettes over 20 minutes, and left for 15 hours) and long-term (laboratory chamber exposed to tobacco smoke for 258 hours over 196 days) THS exposure suggested exposure was related to oxidative stress and DNA damage in human liver cells (Hang et al., 2013). More recently, DNA damage to human dermal fibroblasts (cells within the dermis layer of skin) and neural stem cells was reported after exposure to THS residues extracted from car seat covers and carpets exposed to cigarette smoke over 1 month (Bahl et al., 2015).

In addition, exposure to THS at low concentrations (i.e. THS residues extracted from a laboratory chamber exposed to tobacco smoke for 32 hours over 20 days) caused metabolic changes in two different types of human male reproductive cell lines (Xu et al., 2015). There was no significant difference in cell viability, cell cycle, and apoptosis (programmed cell death) between cells exposed to THS compounds and unexposed cells, prompting the authors to suggest that the metabolic processes in male reproductive cells may be particularly sensitive to THS exposure. While these data from *in vitro* studies suggest that exposure to THS compounds extracted from indoor environments may have some negative effects on human cells, it is difficult to extrapolate the findings from these studies directly to real-world levels of exposure and intake.

Public perceptions of THS exposure

In two qualitative studies of minority groups in the USA, most participants were not necessarily familiar with the term “third-hand smoke”, but could recognise what it referred to once the phrase was explained (Delgado Rendon, Unger, Cruz, Soto, & Baezconde-Garbanati, 2015; Escoffery et al., 2013). Participants reported unpleasant experiences with THS (such as tobacco smoke odour on clothing and in the home) (Delgado Rendon et al., 2015; Escoffery et al., 2013), and felt that THS compromised their quality of life (e.g. unpleasant odour in their home) (Delgado Rendon et al., 2015). Some participants were also concerned about THS exposure in their occupations, for example when cleaning and painting indoor areas that had noticeable tobacco residues (Delgado Rendon et al., 2015).

Other studies have found that while some people believe there are negative health consequences associated with THS, particularly for infants and children (Delgado Rendon et al., 2015; Drehmer et al., 2014; Drehmer et al., 2012; Escoffery et al., 2013; Winickoff et al., 2009), smokers were less likely to believe that THS is harmful to health (Drehmer et al., 2012; Winickoff et al., 2009). Adults and parents who believed that THS was harmful were significantly more likely to have a smoke-free home and/or car policy (Drehmer et al., 2014; Winickoff et al., 2009). Discussing THS with smokers may provide another way to encourage smoking cessation or the adoption of smoke-free homes and cars (Drehmer et al., 2012; Kuschner, Reddy, Mehrotra, & Paintal, 2011; Matt et al., 2011a).

Limiting third-hand tobacco smoke exposure

While the specific health outcomes of THS exposure remain uncertain at present, it may be prudent to limit exposure to THS residues.

The use of smoking bans and policies to reduce THS exposure

Many landlords, accommodation providers (e.g. hotels), and rental car companies have policies limiting smoking in indoor areas in response to resident and customer complaints about the unpleasant perceived effects of THS (including odour, respiratory symptoms, eye irritation, and discolouration of surfaces) (Matt et al., 2011a). Preference for smoke-free indoor areas is also widespread among those living in rental accommodation and multi-unit dwellings. A systematic review of 35 studies conducted in the USA found that the majority of residents of multi-unit dwellings preferred living in smoke-free buildings, and this was particularly so for non-smokers (Snyder, Vick, & King, 2016).

Home, car and accommodation provider smoking bans can partially, but not completely, reduce THS exposure for smokers and non-smokers as THS compounds can infiltrate indoor spaces from outside via air flow, and residues on smokers' clothing and skin (Matt et al., 2014; Matt et al., 2004; Matt et al., 2008; Northrup et al., 2015b). Preliminary data from a small longitudinal study suggest that the surface nicotine in most homes decreased significantly after indoor smoking bans had been in place for 6 months (Northrup et al., 2015b).

There is evidence to suggest that the presence of THS residues in homes and cars makes them less appealing to residents and buyers, and may decrease their value. For example, it was noted in a study of rental accommodation in the USA that residences previously occupied by smokers remained vacant approximately one month longer, and had higher maintenance costs, than residences previously occupied by non-smokers (Matt et al., 2011b). In addition, previous tobacco use in used cars for sale in the USA was associated with a significantly lower asking price (Matt, Romero, et al., 2008). Relatedly, it has been proposed that implementing smoke-free indoor areas policies (for example, in multi-unit dwellings) is cost-effective or cost-saving (Snyder et al., 2016) as the negative sensory impacts of THS, and the need for remediation, are decreased.

Strategies to remove THS residues from indoor environments

THS compounds do not dissipate completely from indoor surfaces of their own accord, therefore it may be desirable or necessary to actively remove the residues to reduce THS exposure (Bahl et al., 2014). Methods of remediation will depend on the level of THS contamination as well as the type of surface or material contaminated (Bahl et al., 2014), however no published current evidence-based recommendations could be sourced for this background paper.

It appears that THS residues can be difficult to remove from the indoor environment (Dreyfuss, 2010; Matt et al., 2011b). THS residues remained in the homes of former smokers even after being vacant for two months and being cleaned for incoming residents, sometimes with new carpet and paint (Matt et al., 2011b). Similarly in used cars, reported common cleaning and ventilation practices (e.g. vacuuming, wiping, opening windows) were not associated with lower surface, dust, or air nicotine levels (Fortmann et al., 2010). In addition, there is no evidence that exposure to THS compounds (particularly nicotine and lower volatility compounds such as PAHs) can be reduced or removed completely by increasing the ventilation of an indoor environment (for example, by using fans, or opening windows) after residues have deposited on surfaces (Kuschner et al., 2011; Singer et al., 2003).

While it may be possible to remove nicotine from smooth surfaces with an acidic cleaning product (as nicotine is an alkaloid), removing THS residues completely from other materials, such as carpet, may be more difficult (Dreyfuss, 2010). One study suggests that washing cotton fabrics in water could be a simple remediation procedure to remove THS residues (Bahl et al., 2014). In this study, the majority of the nicotine, nicotine-related alkaloids and TSNAs were removed from THS-exposed cotton terry cloth after aqueous extraction for one hour in the laboratory (where fabric samples were placed in an aqueous medium and placed on a rotating shaker at room temperature). Increasing the time of extraction to two hours, or decreasing the temperature to 4°C did not significantly change the concentration of chemicals recovered. Lower concentrations of these THS compounds were extracted from polyester fleece, however it could not be determined whether this was because polyester binds less residue than cotton, or that these compounds are more difficult to extract from polyester than from cotton (Bahl et al., 2014). While standard washing procedures may be suitable for small items such as clothes, many household items furnished with fabrics (such as curtains, couches and cushions) are composed of a mix of fibre types, and cannot be thoroughly washed and rinsed easily or frequently.

Conclusions

THS residues are present in the air, dust, and on surfaces of multiple indoor environments where smoking has previously occurred, including homes and cars. These residues contain a variety of tobacco-related compounds, the characteristics of which change over time and under varying environmental conditions. THS residues can remain for weeks to months after smoking has ceased, and it is not yet clear how best to completely remove them from indoor environments.

Exposure to THS will likely be greatest among smokers, those sharing homes with smokers (particularly infants and young children), those inhabiting indoor spaces previously occupied by smokers (e.g. rental accommodation, used cars), and possibly those living in multi-unit dwellings with neighbouring smokers. Sufficient evidence to fully evaluate the potential health consequences of THS exposure is not currently available. However, the public health goals of reducing the prevalence of smoking, and encouraging the adoption of smoke-free indoor and outdoor environments, remain a high priority to decrease tobacco-related harm.

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