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Nicotine on Children's Hands: Limited Protection of Smoking Bans and Initial Clinical Findings

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ABSTRACT

BACKGROUND: Thirdhand smoke (THS) pollutants, such as nicotine, accumulate on the hands of children who live in homes with smokers and are exposed to secondhand smoke. Our objective was to examine whether levels of hand nicotine in exposed children are associated with demographics, environmental factors, and clinical findings.

METHODS: Participants were caregivers who smoke and children (mean age (SD) = 2.6 (3.7) years) who were part of an ongoing 2-group, randomized controlled trial of an emergency department–based tobacco cessation intervention (N = 104). The primary outcome measure was nicotine on the child's hand. Caregivers reported demographics and smoking patterns; children's medical records were abstracted for chief complaint, medical history, and diagnoses.

RESULTS: All children had detectable hand nicotine (geometric mean [GeoM] = 86.2 ng/wipe; range = 3.5-2, 190.4 ng/wipe). Children in the age group of 2 to 4 years old (GeoM = 185.6 ng/wipe) had higher levels than the children in the age groups of 0 to 1 (GeoM = 68.9 ng/wipe, $P < .001$), 5 to 9 (GeoM = 77.9 ng/wipe, $P = .04$), and 10 to 15 years old (GeoM = 74.2 ng/wipe, $P = .048$). Children whose caregivers smoked 6 to 14 (GeoM = 97.2 ng/wipe, $P = .047$) and 15 to 40 cigarettes/day (GeoM = 124.0 ng/wipe, $P = .01$) had higher levels than children whose caregivers smoked 1 to 5 cigarettes/day (GeoM = 59.7 ng/wipe). Children with 6 to 14 cigarettes/day (GeoM = 163.11 ng/wipe, $P = .007$) and 15 to 40 cigarettes/day (GeoM = 186.1, $P = .003$) smoked inside the home by all smokers had significantly higher levels than homes with 0 cigarettes (GeoM = 81.3 ng/wipe). Similar differences in hand nicotine levels were found for smoking frequency of all household members in any location. Children with complaints of cough/congestion (GeoM = 97.7 ng/wipe) had higher levels than those without cough/congestion (GeoM = 59.0 ng/wipe, $P = .01$).

CONCLUSIONS: The high hand nicotine levels in children whose caregivers do not necessarily smoke indoor demonstrate that indoor smoking bans do not safeguard against THS exposure and the associations with increased home smoking activity indicate that hand wipes may be a noninvasive way to characterize children's exposure. The findings of associated cough and congestion with higher THS levels need to be examined further.

KEYWORDS: thirdhand smoke, secondhand smoke, tobacco smoke, children

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Introduction

Thirdhand smoke (THS) is the persistent residue that results from secondhand smoke (SHS) that accumulates in dust, objects, and on surfaces in environments where tobacco has been used. Children are one of the most vulnerable populations to THS exposure and its effects, but the mechanisms by which they are exposed and the clinical effects of exposure and harm are largely unknown.[1] Although there is concern that higher levels of THS and SHS exposure as measured by self-report are associated with increased respiratory symptoms (eg, cough) in children,[2] these associations have not been biochemically validated or confirmed with child medical record review. As nicotine, a THS pollutant, accumulates on the hands of children who live in homes with varying levels of smoke exposure,[3] and even on surfaces and dust in homes of smokers that have indoor smoking bans,[4–6] the measurement of hand nicotine in clinically ill children provides a way to assess both stable and modifiable environmental factors that are associated with THS exposure and how THS is associated with clinical illness.

Recently, we reported high levels of nicotine on ill children's hands and an association with hand nicotine levels and children's overall tobacco smoke exposure.[3,7] However, we analyzed a small sample and thus we were not able to assess whether there were any potentially modifiable risk factors that are associated with hand nicotine levels nor were we able to assess whether hand nicotine levels were associated with clinical

illness. Thus, in an effort to better understand the associations of THS pollution in children, the primary objectives of this study were to examine the levels of hand nicotine in exposed children and how levels are associated with sociodemographic factors, smoking behavior, and child tobacco smoke exposure (TSE) patterns, and environmental characteristics. Secondary aims were to explore whether THS pollutants levels are associated with clinical illness and whether these levels varied over time. We hypothesized that children who lived in apartments or homes with more smokers or greater cigarette consumption would have higher THS levels.

Methods

A convenience sample of nonsmoking pediatric patients (N = 104), aged 0 to 17 years, presenting to the Pediatric Emergency Department (PED) during April 2016 and August 2017 at Cincinnati Children's Hospital Medical Center (CCHMC) with a potentially TSE-related complaint were eligible to participate in a 2-group, randomized controlled trial of a tobacco cessation intervention for caregivers who smoke (http://clinicaltrials.gov [NCT02531594]).[3] The CCHMC institutional review board approved caregiver consent and child assent on children 11 years of age or older were obtained.

Outcome variable

Trained research staff obtained hand wipe samples by wiping the palm and volar aspect of all fingers of children's dominant hand; wipes were analyzed for hand nicotine, the main outcome variable; field blanks were collected to adjust for potential sample contamination (median [Mdn] = 7.57 ng/wipe.[8] A subsample of children (n = 25) had hand nicotine obtained during home visits at 6 weeks (T1) after the baseline index visit (T0). Field blanks for samples at 6 weeks were also collected to adjust for potential sample contamination (Mdn = 9.34). All reported hand nicotine levels at T0 and T1 have been corrected for nicotine levels measured on the field blanks.

Exposure variables

Exposure variables were caregiver-reported smoking behavior and child TSE patterns including electronic cigarette use and the number of (1) smokers who lived with the child; (2) cigarettes smoked per day by caregivers; (3) cigarettes smoked around the child by all smokers (eg, mother, father, caregiver's significant other, siblings, friends, visitors, relatives) in any location including the home, car, and other locations; and (4) cigarettes smoked around the child inside the home by all smokers. Caregivers also self-reported household characteristics including housing type (ie, single-family home, multifamily apartment) and cleaning frequency of their homes.

Children's medical records were abstracted for TSE-related complaints (ie, congestion/cough, difficulty breathing, wheezing, otalgia), past medical histories (PMH), and discharge diagnoses (ie, asthma, bronchiolitis, otitis media).

Sociodemographic variables included child age, child sex, child race, insurance type, and family income level.

Statistical Analyses

We tested a series of linear regression models to address our primary aim and examine the association between the outcome variable (ie, hand nicotine) and sociodemographic and exposure-related explanatory variables (ie, smoking behavior and child TSE patterns, household characteristics, and TSE-related complaints, PMH, and diagnoses). To address the skewed distributions of hand nicotine, we log-transformed this variable. In addition, we fitted a polynomial regression model to examine the potentially nonlinear relationship between hand nicotine levels and child age and found a quadratic association showing highest nicotine levels in 2- to 4-year olds. To represent this pattern, we included age as a categorical variable with 4 groups in our analyses.

We built 10 separate multiple regression models to explore the relationship between log-nicotine values, our outcome variable, and TSE-related complaints (ie, congestion/cough, difficulty breathing, wheezing, otalgia), PMH (ie, asthma, bronchiolitis, otitis media), and discharge diagnosis (ie, asthma, bronchiolitis, otitis media) while adjusting for child age and number of cigarettes/day reported by caregivers in each model because these 2 variables were the only exposure variables significantly related to the outcome variable. For follow-up exploratory analyses, we also built a series of multinomial regression models after trichotomizing our outcome variable, hand nicotine, to assess the relationship between exposure groups and TSE-related complaints, PMH, and discharge diagnosis. Hand nicotine values were trichotomized for these particular models to contrast children with the lowest (<40 ng/wipe) and highest levels (>100 ng/wipe). Type 1 error was .05 (2-tailed).

Results

The mean (SD) age of children was 2.6 (3.7) years; 52% were men; 54% were black, non-Hispanic; 64% had a household income of <US $15 000. Most of the children (67%) lived with 1 smoker (see Table 1). At T0, all children had detectable hand nicotine (level of quantitation = 0.30 ng nicotine) ranging up to 2190.4 ng/wipe (geometric mean [GeoM] = 90.0 ng/wipe, 95% confidence interval [CI] = 71.3-113.6, Mdn = 97.2 ng/wipe, interquartile range = 44.6-183.2). All enrolled children had a potentially TSE-related chief complaint with the top 3 complaints being cough/congestion (n = 87, 83.7%), otalgia (n = 33, 31.7%), and wheezing or difficulty breathing (n = 31, 29.8%). The most common PMH was asthma (19.2%). The 3 most common discharge diagnoses were upper respiratory infections (n = 54, 51.9%), otitis media (n = 26, 25.0%), and asthma (n = 18, 17.3%).

Table 1. Hand wipe nicotine concentrations and participant characteristics.

CHARACTERISTIC	NO. (%)	HAND NICOTINE CONCENTRATION FROM HAND WIPES[a]		
		GEOMEAN (95% CI)	MEDIAN (IQR)	*P* VALUE[b]
Child age, M (SD)	2.6 (3.73)			
25th-50th-75th	0-1-3			
0-1 y	59 (56.7)	68.9 (51.8-91.4)	73.0 (41.9-152.9)	**<.001**
2-4 y	26 (25.0)	185.6 (106.9-321.9)	179.7 (108.1-387.0)	Ref.
5-9 y	11 (10.6)	77.9 (49.3-122.9)	102.2 (42.8-117.4)	**.04**
10-15 y	8 (7.7)	74.2 (27.8-195.3)	98.9 (52.8-134.9)	**.048**
Child sex				
Male	54 (51.9)	95.5 (66.2-137.5)	103.4 (47.0-212.5)	Ref.
Female	50 (48.1)	84.5 (63.0-113.2)	91.5 (44.6-153.7)	.60
Child race				
White, non-Hispanic	39 (39.4)	96.5 (62.6-148.4)	86.2 (46.1-204.6)	Ref.
Black, non-Hispanic	53 (53.5)	89.4 (64.7-123.5)	102.9 (41.9-187.6)	.77
Other	7 (7.1)	79.6 (41.5-151.9)	92.4 (74.1-109.9)	.70
Insurance type				
Public/self-pay	95 (91.3)	86.6 (67.8-110.4)	91.6 (44.4-168.4)	Ref.
Commercial	9 (8.7)	135.8 (54.3-337.5)	180.3 (47.5-262.4)	.28
Income level				
<US $15 000	66 (63.5)	80.1 (59.6-107.5)	86.3 (40.2-162.5)	Ref.
>US $15 000	38 (36.5)	110.2 (74.7-162.5)	105.5 (51.1-226.5)	.19
No. of smokers living with child				
1 smoker	70 (67.3)	83.4 (62.1-112.0)	77.9 (40.2-172.2)	Ref.
2-3 smokers	34 (32.7)	105.2 (71.2-155.1)	108.5 (55.1-185.7)	.36
No. of cigarettes/day by caregiver, M (SD)	11.0 (7.20)			
25th-50th-75th	5.25-10-15			
1-5 cigarettes	26 (25.0)	54.9 (32.9-91.1)	57.6 (26.8-121.7)	Ref.
6-14 cigarettes	50 (48.1)	97.2 (69.5-135.7)	105.5 (51.1-164.2)	**.047**
15-40 cigarettes	28 (26.9)	124.0 (81.8-187.7)	110.2 (61.3-300.9)	**.01**
No. of cigarettes smoked around the child by all smokers in any location, M (SD)				
25th-50th-75th	0-4-10.3			
0 cigarettes	23 (28.0)	82.3 (46.1-146.0)	74.7 (41.9-221.5)	Ref.
1-5 cigarettes	24 (29.3)	76.3 (43.4-133.7)	77.8 (42.0-237.1)	.83
6-14 cigarettes	20 (24.4)	97.3 (63.8-148.1)	108.5 (41.0-169.9)	.64
15-57 cigarettes	15 (18.3)	201.7 (119.4-340.3)	164.6 (91.6-302.4)	**.02**
No. of cigarettes smoked inside the home by all smokers, M (SD)				
25th-50th-75th	0-2-10			
0 cigarettes	33 (40.7)	59.7 (40.9-86.9)	61.2 (39.0-124.7)	Ref.

(Continued)

Table 1. (Continued)

CHARACTERISTIC	NO. (%)	HAND NICOTINE CONCENTRATION FROM HAND WIPES[a]		
		GEOMEAN (95% CI)	MEDIAN (IQR)	*P* VALUE[b]
1-5 cigarettes	21 (25.9)	99.6 (56.4-175.2)	121.6 (41.4-300.2)	.11
6-14 cigarettes	14 (17.3)	163.1 (73.8-358.8)	117.4 (71.8-294.7)	**.007**
15-40 cigarettes	13 (16.0)	186.1 (117.3-294.9)	163.1 (112.0-301.7)	**.003**
Daily electronic cigarette use				
No	75 (93.8)	86.8 (66.0-114.0)	91.6 (42.9-161.9)	Ref.
Yes, sometimes	5 (6.3)	157.2 (87.5-281.6)	172.2 (108.0-184.2)	.27
Housing type				
Single-family home	52 (50.0)	75.6 (53.6-106.5)	83.7 (43.4-122.6)	Ref.
Multifamily or apartment building	52 (50.0)	107.1 (77.8-147.4)	124.9 (59.6-230.1)	.14
Cleaning frequency				
Daily	71 (68.3)	101.6 (75.1-137.5)	102.9 (48.5-256.3)	Ref.
Several times a week or less	33 (31.7)	69.3 (49.1-97.5)	74.4 (43.9-125.1)	.13

Abbreviation: IQR, interquartile range.
N = 104; percent refers to valid percent.
[a]All reported hand nicotine levels have been corrected for nicotine levels measured on field blanks, see text.
[b]*P* values refer to linear regression analysis results.
Bold values indicate $P < .05$.

Linear regression results indicated that children aged 2 to 4 years (GeoM = 185.6 ng/wipe) had higher hand nicotine than children aged 0 to 1 years (GeoM = 68.9 ng/wipe, $P < .001$), 5 to 9 years (GeoM = 77.9 ng/wipe, $P = .04$), and 10 to 15 years (GeoM = 74.2 ng/wipe, $P = .048$; Table 1). Children whose caregivers smoked 15 to 40 cigarettes/day (GeoM = 124.0 ng/wipe, $P = .01$) and 6 to 14 cigarettes/day (GeoM = 97.2 ng/wipe, $P = .047$) had greater hand nicotine than children whose caregivers smoked 1 to 5 cigarettes/day (GeoM = 54.9 ng/wipe). Compared to environments where 0-5 cigarettes/day were smoked around the child (GeoM=79.2ng/wipe), hand nicotine levels were significantly elevated when 6–14 cigarettes/day (GeoM=97.3ng/wipe, $p = .51$), and 15–57 cigarettes/day (GeoM=201.7ng/wipe, $p = .008$) were smoked. There were progressively higher levels of hand nicotine with the lowest levels in children who lived in homes with 0 cigarettes/day smoked inside the home by all smokers (GeoM = 59.7 ng/wipe) followed by 1 to 5 cigarettes/day (GeoM = 99.6 ng/wipe, $P = .11$), 6 to 14 cigarettes/day (GeoM = 163.11 ng/wipe, $P = .007$), and 15 to 40 cigarettes/day (GeoM = 186.1 ng/wipe, $P = .003$). Although not statistically significant, children living in multiunit housing (MUH)/apartments had 42% higher levels (GeoM = 107.1 ng/wipe, $P = .08$) than children in single-family homes (GeoM = 75.6 ng/wipe).

At T0, with log-transformed nicotine and controlling for age and caregiver-reported cigarettes/day, multiple regression results indicated that participants with a cough/congestion complaint (GeoM = 97.7 ng/wipe) had greater hand nicotine than those without a cough/congestion complaint (GeoM = 59.0 ng/wipe, $P = .01$). Follow-up multinomial regression analysis results to contrast maximally different exposure groups, while controlling for age and caregiver-reported cigarettes/day, indicated that participants with hand nicotine >100 ng/wipe were 5.90 times more likely (95% CI = 1.43-28.82, $P = .02$) to have cough/congestion than participants with nicotine <40 ng/wipe. No significant differences were found between the <40 ng/wipe and 40 to 100 ng/wipe groups and no associations were found with other TSE-related complaints, PMHs, and discharge diagnoses.

All participants in the T1 subsample (n = 25) had detectable hand nicotine ranging from 12.9 to 2606.5 ng/wipe (GeoM = 160.8 ng/wipe). Participants had greater mean hand nicotine at T1 than T0 (GeoM = 86.4 ng/wipe; $t[df = 24] = 2.51$, $P = .02$). We explored the relationship between T1 log-nicotine and TSE-related clinical variables while including age and cigarettes/day. Those with PMHs or diagnoses of asthma and/or bronchiolitis ($P = .02$) had greater hand nicotine than those without these PMHs or diagnoses.

Discussion

This study extends our prior work[3] with a larger sample, replicating that ill pediatric patients living in smokers' homes had high tobacco smoke toxicants on their hands during their PED visit. We again found that children's hand nicotine concentrations measured at T0 were over 3 times higher than

those in nonsmoking adults living with smokers (GeoM = 25.6 ng/wipe).[5,7,9] In this study, we found that children with T0 and T1 values had mean levels of 90.0 ng/wipe in the PED and 160.8 ng/wipe at home; differences may be due to handwashing in the hospital versus home setting as increased handwashing frequency is associated with lower flame retardants on hands in other studies.[10,11] Handwashing may be an easy, modifiable behavior that can decrease children's THS exposure and hand nicotine levels obtained in the PED may underestimate exposure. However, this possibility needs to be studied further. We present new findings that 2- to 4-year olds had the highest THS levels, possibly reflecting increased mobility, exploratory behavior, decreased sleeping time, and increased contact with polluted surfaces compared with infants and older children; alternatively, this can reflect decreased handwashing. This parallels findings that older, active toddlers had higher levels of flame retardants on their hands compared with younger children.[10,12,13]

We observed progressively higher hand nicotine in patients who had a higher number of cigarettes/day smoked by their caregivers, number of cigarettes/day smoked around them by all smokers in any location, and number of cigarettes/day smoked by all smokers inside the home. Compared with 0 cigarettes/day, we found a 76% significant mean difference in hand wipe values for children with caregivers who smoked 6 to 14 cigarettes/day and a 125% mean difference for children with caregivers who smoked 15 to 40 cigarettes/day. We also found a significant mean difference of 145% in hand wipe levels for children around 0 cigarettes/day and 15 to 57 cigarettes/day smoked by any smoker in any location. A significant mean increase was also seen based on the number of cigarettes/day smoked by all smokers inside the home with a 173% significant mean difference in hand wipe values for children exposed to 6 to 14 cigarettes/day and a 211% increase in hand wipe levels for children exposed to 15 to 40 cigarettes/day compared with children exposed to 0 cigarettes/day. This supports previous work that found that homes in which more cigarettes were smoked had higher home surface nicotine levels[4-6] and is consistent with our hypothesis that greater indoor smoking leads to greater THS deposition and pollution. A notable finding not previously examined was that although 28% and 41% of caregivers reported that no cigarettes were smoked around their child in any location or inside the home regardless of smoker, hand nicotine still averaged 82.3ng/ml and 59.7ng/ml, respectively. Thus, although setting up home and car smoking bans is an important behavior that clinicians should encourage in caregivers who smoke as a way to help protect their children from TSE,[5-7,14] this behavior alone is not enough to adequately protect children from obtaining nicotine on their hands. Unfortunately, many other environmental sources of THS pollution, such as settled house dust, and home surfaces, such as doors, windows, furniture, toys, and fabrics, may likely contribute to children's overall THS pollution levels via hand-to-mouth behaviors even when there are home smoking bans.[5,15]

Although all children had TSE-related complaints, there were high rates of TSE-related PMHs and discharge diagnoses. We provide initial findings that there may be an association between high hand nicotine and complaints of cough/congestion in the T0 sample and with TSE-related PMHs and diagnoses in the T1 subsample. Findings should be considered with caution and independent replication is warranted. However, these findings align with research demonstrating respiratory symptoms such as cough associated with sources of self-reported, but not biochemically validated, THS exposure in adolescent nonsmokers.[2,16]

The limitations of this study include lack of a control group of healthy children without SHS or THS exposure. As we wiped the entire hand as opposed to previous work where adults' index fingers were wiped, direct comparisons are difficult; however, findings of higher levels in younger children with smaller hands compared with the older children and levels over 7 times higher in children in the 2- to 4-year-old category (GeoM = 185.6 ng/wipe) compared with adult nonsmokers cannot be explained by this methodology alone.[5–7] There was a wide age range of children and TSE patterns vary between young children who are exposed to higher levels of tobacco smoke in the home compared with older children and adolescents who spend more time away from the home. In addition, the handwashing practices of all participants were not assessed; thus, it is unknown whether handwashing affected our results, but this will be evaluated in future studies.

Our findings suggest that THS residue on children's hands increases with indoor smoking, but lack of indoor smoking is not a safeguard against THS exposure. This is expected because THS accumulates when cigarettes are smoked indoors and persists long after smoking has occurred and because THS and SHS contribute to children's overall TSE.[3] Hand wipes may provide a noninvasive method to characterize children's proximal exposure to environmental pollutants in more than one microenvironment.[8,13] Future work should explore the associations of hand nicotine and age to determine how children's changing interactions with their environment and behaviors contribute to increased nicotine in 2- to 4-year olds, whether handwashing decreases the risk, and whether increased levels are associated with increased SHS-related clinical illnesses. Research is needed to evaluate the associations of nicotine and sources of exposure that can be modified (eg, smoking cessation, comprehensive strict indoor smoking bans for all residents/visitors, smoking bans in MUH, never smoking around the child in any location), and targeted (eg, carpets, toys, upholstery, blankets) in future TSE remediation efforts to decrease children's exposure.

Author Contributions

MMG conceived the study, overall study aims, study design, and wrote the first draft of the paper. GEM guided the sample and data collection protocol and developed the specific study aims. GEM and ALM conducted the statistical analysis and interpreted the data. EH designed and supervised laboratory analyses and PJEQ provided input on analyses and interpretation of data. All authors made critical comments and revised drafts of the paper. All authors read and approved the final manuscript.

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