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Handwashing Results in Incomplete Nicotine Removal from Fingers of Individuals who Smoke: A Randomized Controlled Experiment

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Abstract

Objective: Tobacco residue, also known as third-hand smoke (THS), contains toxicants and lingers in dust and on surfaces and clothes. THS also remains on hands of individuals who smoke, with potential transfer to infants during visitation while infants are hospitalized in neonatal intensive care units (NICUs), raising concerns (e.g., hindered respiratory development) for vulnerable infants. Previously unexplored, this study tested handwashing (HW) and sanitization efficacy for finger-nicotine removal in a sample of adults who smoked and were visiting infants in an NICU.
Study Design: A cross-sectional sample was recruited to complete an interview, carbon monoxide breath samples, and three nicotine wipes of separate fingers (thumb, index, and middle). Eligible participants ($n = 14$) reported current smoking (verified with breath samples) and were randomly assigned to 30 seconds of HW ($n = 7$) or alcohol-based sanitization ($n = 7$), with the order of finger wipes both counterbalanced and randomly assigned. After randomization, the first finger was wiped for nicotine. Participants then washed or sanitized their hands and finger two was wiped 5 minutes later. An interview assessing tobacco/nicotine use and exposure was then administered, followed by a second breath sample and the final finger wipe (40–60 minutes after washing/sanitizing).

Keywords

- thirdhand smoke
- THS
- neonatal ICU
- THS removal
- handwashing
- sanitizer

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Results: Generalized linear mixed models found that HW was more effective than sanitizer for nicotine removal but failed to completely remove nicotine.
Conclusions: Without proper protections (e.g., wearing gloves and gowns), NICU visitors who smoke may inadvertently expose infants to THS. Research on cleaning protocols are needed to protect vulnerable medical populations from THS and associated risks.

Key Points

- NICU infants may be exposed to THS via visitors.
- THS is not eliminated by HW or sanitizing.
- THS removal protections for NICU infants are needed.

Thirdhand smoke (THS) is the toxic residue that remains in environments where tobacco has been smoked. In addition to toxicants found in tobacco, new pollutants can be created through interaction with other indoor air compounds.[1] THS is easily transported to new environments (e.g., on skin or clothing) by individuals who use tobacco or are exposed to tobacco smoke or nicotine vapor[2–6] which has propelled research on THS in medical settings.[3–5,7,8] Health risks from THS exposure are accumulating from in vitro studies, animal models, and human research,[9–12] and include DNA damage,[13] impaired wound healing,[14] hindered respiratory development,[15] and increased respiratory symptoms in THS-exposed children.[16,17] These risks are potentially most concerning for preterm and other vulnerable infants admitted to neonatal intensive care units (NICUs), as they are at increased risk for many health problems,[18,19] including respiratory diseases (e.g., bronchopulmonary dysplasia,[20–22] poor neurodevelopmental outcomes,[21] and rehospitalizations[23–25]).

Individuals, especially children, are exposed to THS through multiple routes (i.e., ingestion, inhalation, and dermal uptake).[26] Our own research has documented THS contamination in NICU settings, as THS residue is transported and deposited on NICU surfaces by visitors and staff,[3,17] and we documented infant exposure (as measured by urine cotinine) while infants are hospitalized.[5,17] We also found associations of THS exposure in the NICU with infants' gut microbiome composition,[27] in line with studies reporting associations of THS with clinical outcomes in older children.[28,29] However, little research has been done on how to protect hospitalized pediatric patients while being held and touched by parents and other visitors from THS coming from contaminated individuals. Indeed, to inform hospital policies on THS-protective protocols, we know of only a single study with tobacco harvesters who demonstrated reductions in (but incomplete removal of) nicotine from harvesters' hands after rigorous handwashing (HW).[30] Nicotine is commonly found on hands and fingers of individuals who smoke[31] and THS-exposed children,[4,28] as is toxic polycyclic aromatic hydrocarbons.[32] Our primary aim was to explore the efficacy of hand washing and ethyl alcohol–based hand sanitizer (HW/sanitization [HW/S]) for finger-nicotine removal in a sample of family members who smoked and were visiting infants in a NICU. We hypothesized that nicotine would remain on participants' fingers, regardless of HW/S attempts, and that greater finger-nicotine levels would remain after alcohol sanitization compared with hand washing.

Materials and Methods

Our institution (HSC-MS-15–0614) and hospital NICU Institutional Review Board (IRB) approved this trial, registered on clinicaltrials.gov (NCT04155697). All measures, conditions, and analyses are reported.

Participants and Procedure

Participants were recruited from a large, metropolitan children's hospital, with a level-4 NICU (1,400 admissions/year), from March 2017 until October, 2018. All bedside visitors (i.e., parents and other family members) present during screening for our parent study[3,17] were eligible for the HW/S study (►Fig. 1). The primary aims of the parent study were broadly focused on assessing THS contamination and infant THS exposure in the NICU,[17] and HW/S study participants were recruited as a convenience sample from participants in the main study, until the parent trial finished recruitment. Research assistants screened household nicotine/tobacco use (i.e., any member of the home used tobacco/nicotine) with a well-validated approach[5,33,34] and fully assessed individual participant nicotine/tobacco use during an interview. Eligible HW/S participants reported current smoking (verified by exhaled carbon monoxide [CO] values of $\geq$7 parts per million [ppm] which is highly sensitive to recent smoking[35,36]), as individuals who report current smoking tend to have significantly more nicotine on their hands compared with nonsmokers.[5,17] Individuals unable to complete assessments in English were excluded. Research assistants screened bedside visitors several times per week and counterbalanced starting times and locations daily. All participants gave consent and received $10 for participation.

Procedures included an interview which assessed participant and household tobacco use and exposure,[3,17] and exhaled CO breath samples. After CO validation of smoking status,

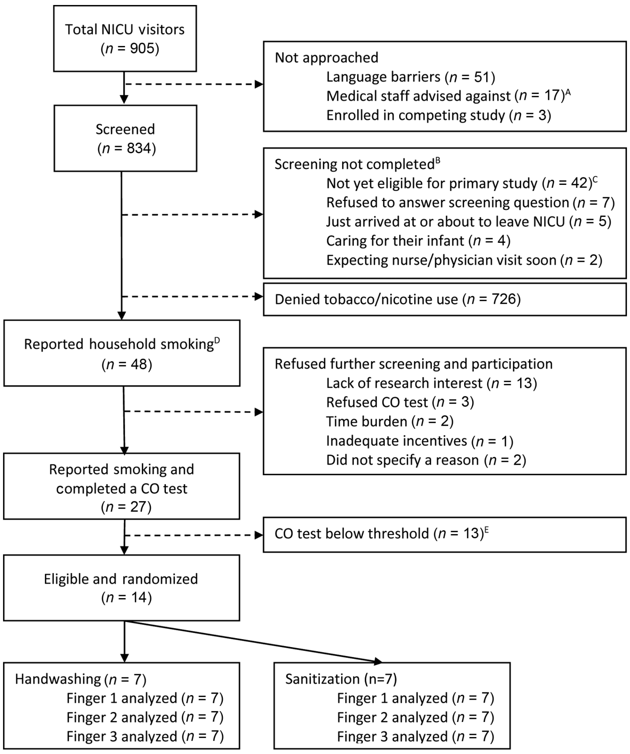


Fig. 1 Study flow diagram. Parents and other family visitors to infants hospitalized in the NICU were screened and recruited to the handwashing/sanitization (HW/S) study as a convenience sample from participants recruited for primary aims addressed in our parent study (broadly assessing THS contamination and infant THS exposure in the NICU between March, 2017 and October, 2018). "CO" = carbon monoxide. [A]E.g., due to infant illness or recent family decision to withdraw health-supporting measures for an infant likely not to survive to discharge. [B]None of these participants were fully screened for personal (current) smoking status or completed a CO-breath sample, necessary for determining study eligibility. Specifically, many of them refused to participate after completing household tobacco/nicotine use screening. [C]A majority of these parents were first screened for household tobacco/nicotine use before their infant had reached postnatal day 5 (i.e., the first day a participant could complete a protocol for the primary aims of the parent study) and the parent could not be re-contacted on a later date. [D]Parents and family members were first screened for household tobacco/nicotine use (i.e., any member of the home uses tobacco/nicotine) and individual smoking was fully assessed during participation in the interview that all participants completed for the handwashing/sanitization study and parent study procedures. [E]The CO-breath threshold to be eligible was ≥11 ppm when the study began recruiting and was lowered to ≥7 ppm in consultation with the investigative team and after receiving IRB approvals, to increase the likelihood of identifying individuals who currently smoked. IRB, institutional review board; NICU, neonatal intensive care unit; THS, thirdhand smoking.

HW/S study procedures consisted of (blinded) research assistants opening an opaque envelope to randomly assign the counterbalanced order of three separate finger wipes (thumb, index, and middle) and condition (hand washing or sanitization [via 1:1 allocation]); the principal investigator (PI) used the, "rand ()" function in Microsoft Excel to generate and secure the random allocation sequences. Next, finger one (F1) was wiped and then participants washed or sanitized for 30 seconds (timed by research assistants) with 2% chlorohexidine gluconate soap (Ecolab) or 62% ethyl alcohol–based hand sanitizer (Ecolab). Finger two (F2) was wiped approximately 5 minutes after washing or sanitizing (measuring skin nicotine immediately after air/towel drying), and then participants completed the interview. Participants were asked to avoid washing or sanitizing between the second- and third-finger wipe, and participants were instructed not to smoke or vape, use smokeless tobacco, or be exposed to smoke/vapor during this time (if they needed to leave the room before the third-finger wipe). CO breath tests were readministered immediately before completing the third-finger wipe (~40–60 minutes after handwashing/sanitization [HW/S]) to assess participant compliance with instructions to abstain from nicotine/tobacco use and exposure (see Data Analyses section for participant protocol violations). The third wipe was used to measure nicotine stored in skin recontaminating the skin's surface.

Measures

Finger-wipe procedures[31,37–39] are well established[40] and have been used to measure finger nicotine for NICU visitors[5,17] and medical staff[3] as a potential THS-exposure route for infants. Briefly, finger nicotine was the primary outcome and samples were obtained by wetting a screened cotton wipe with a solution (of distilled water and 1% ascorbic acid) and wiping the entire finger surface. Unstandardized (raw) finger levels are reported in nanograms (ng). Finger area was measured to allow standardized comparisons between fingers and other surfaces (e.g., furniture, cars, and walls) often reported in micrograms per square meter (μg/m^2).[3]

Field blanks were collected during sampling, consistent with Quintana et al.[39] Prepared blanks were wetted with the water and ascorbic acid solution and exposed to the room air but not used to wipe a finger. Blank values were subtracted from finger samples to account for nicotine present in sampling materials and the environment (air). The geometric mean of analyzed field blanks was 2.23 ng/wipe.

Interviews assessed participant/household characteristics, including NICU visitation (e.g., number of days [out of past 7] visited, visitation length, and total number of visitors), infant holding (time), and HW/S practices and glove/gown use (►**Table 1**), as well as other areas measured for primary study aims.[17] We measured current and life-time cigarette smoking and vaping (e.g., e-cigarette use), as well as cigarettes/day.[5,33]

Data Analyses

One participant in the sanitization condition left the NICU before completing finger-wipe three. Further, two participants ($n = 1$ per condition) had their third-finger wipe dropped from data analyses due to protocol violations. Specifically, a sanitization participant applied additional sanitizer between finger wipes two and three, while a HW participant smoked a cigarette and washed and sanitized their hands between finger wipes two and three.

Generalized linear mixed modeling evaluated changes in standardized finger nicotine as a function of the main effects and interaction between time (across three wipes) and group

Table 1 Participant and household characteristics by randomized condition

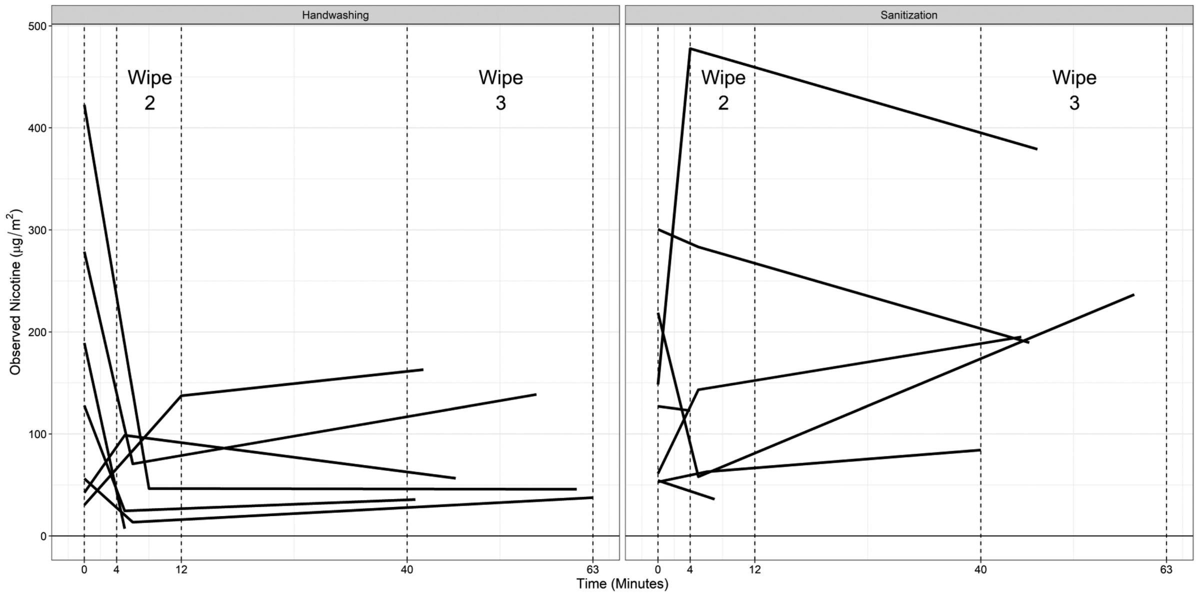
Characteristic	Soap condition ($n = 7$)	Sanitization condition ($n = 7$)
Race/ethnicity, n (%)		
Black/African American	5 (71.4%)	6 (85.7%)
Hispanic	0 (0.0%)	1 (14.3%)
White, non-Hispanic	2 (28.6%)	0 (0.0%)
Participant age (y) Mean (SD)	37.9 (11.1)	40.4 (11.1)
Highest education (y) Mean (SD)	12.9 (0.9)	11.5 (1.4)
Female (participant), n (%)	2 (28.6)	7 (100)
Relationship status, n (%)		
Married	0 (0.0%)	2 (33.3%)
Living together but not married	6 (85.7%)	1 (16.7%)
Single	1 (14.3%)	2 (33.3%)
Divorced/separated/widowed	0 (0.0%)	1 (16.7%)
Relationship to Infant, n (%)		
Mother	1 (14.3%)	3 (42.9%)
Father	5 (71.4%)	0 (0.0%)
Other relative	1 (14.3%)	4 (57.1%)
Number of adults ≥18 years in home Mean (SD)	2.6 (1.4)	2.2 (0.8)
Typical cigarettes/day (participant) Mean (SD)	9.9 (5.7)	6.9 (2.0)
Cigarettes on day of assessment (participant) Mean (SD)	3.6 (2.2)	2.6 (1.1)
ENDS status (participant), n (%)		
Current ENDS use	0 (0.0%)	0 (0.0%)
Former ENDS use	3 (42.9%)	3 (42.9%)
Never used ENDS	4 (57.1%)	4 (57.1%)
Tobacco users reported in home (participant and others), n (%)		
One	3 (42.9%)	2 (28.6%)
Two or more	4 (57.1%)	5 (71.4%)
Typical cigarettes/day (all other household members) Mean (SD)	15.8 (16.4)	6.4 (3.5)
Cigarettes/day by all household members, n (%)		
< 10 cigarettes/day	1 (14.3%)	3 (42.9%)
≥ 10 cigarettes/day	6 (85.7%)	4 (57.1%)
Glove use, n (%)		
Never	7 (100%)	4 (66.7%)
Sometimes	0 (0.0%)	2 (33.3%)
Always	0 (0.0%)	0 (0.0%)
Gown use, n (%)		
Never	1 (14.3%)	1 (16.7%)
Sometimes	3 (42.9%)	3 (50.0%)
Always	3 (42.9%)	2 (33.3%)
Handwashing/sanitization practices, n (%)		
Never wash/always sanitize	0 (0.0%)	0 (0.0%)
Sometimes wash/mostly sanitize	2 (28.6%)	0 (0.0%)

Table 1 (*Continued*)

Characteristic	Soap condition ($n=7$)	Sanitization condition ($n=7$)
Wash half the time/sanitize half the time	2 (28.6%)	6 (100%)
Mostly wash/sometimes sanitize	3 (42.9%)	0 (0.0%)
Always wash/never sanitize	0 (0.0%)	0 (0.0%)
Days participant visited (out of past 7) Mean (SD)	6.0 (1.4)	4.9 (2.1)
Visitation length (hours/day) Mean (SD)	8.9 (5.2)	6.6 (4.6)
Infant held (minutes/day) Mean (SD)	60.0 (34.6)	68.6 (106.4)
CO (ppm) Mean (SD)	15.9 (9.2)	16.3 (8.3)
CO (ppm), second reading Mean (SD)	14.3(10.8)	14.3(8.6)
Finger 1		
Surface area (cm^2) Mean (SD)	51.2 (8.3)	42.2 (4.9)
Unstandardized nicotine (ng/finger) Mean (SD)	823.6 (680.5)	602.8 (443.8)
Unstandardized nicotine (ng/finger) Median (IQR)	837.7 (164.4–1,365.5)	537.9 (232.5–1,047.5)
Unstandardized nicotine (ng/finger) Geometric mean	561.9	468.5
Finger 2		
Surface area (cm^2) Mean (SD)	52.6 (9.1)	44.1 (7.7)
Unstandardized nicotine (ng/finger) Mean (SD)	300.2 (244.7)	773.8 (761.8)
Unstandardized nicotine (ng/finger) Median (IQR)	263.9 (72.8–475.4)	599.7 (258.0–1,133.6)
Unstandardized nicotine (ng/finger) Geometric mean	194.9	512.4
Finger 3		
Surface area (cm^2) Mean (SD)	50.2 (5.5)	41.1 (5.3)
Unstandardized nicotine (ng/finger) Mean (SD)	391.7 (267.8)	934.3 (576.9)
Unstandardized nicotine (ng/finger) Median (IQR)	243.4 (201.5–720.1)	787.8 (701.0–1,024.2)
Unstandardized nicotine (ng/finger) Geometric mean	326.9	795.1

Abbreviations: CO, carbon monoxide; HW/S, handwashing/sanitization; ENDS, electronic nicotine delivery systems; IQR, interquartile range; SD, standard deviation.
Note: Data were collected between March, 2017 and October, 2018. Where categories do not add up to the total sample size, the remainder represent missing data. Two questions each were used to assess gown and glove use, separately.

(HW vs. sanitization) with a level-2 random intercept to account for correlated observations. Bayesian statistical inference[41,42] directly provided model-specific probabilities that predictor effects on the outcome existed. Models used vague, neutral priors (b = ~Normal [$\mu=0$, $\sigma^2=1e5$], sigma = ~Student-*t* [$\mu=0$, $\sigma^2=1e5$]) to maximize the influence of the data on posterior probabilities (PP).[43] A threshold of evidence for the PP was established to signify support for an alternative hypothesis (i.e., a model effect is non-0). This threshold was set to PP = 75% for the present analysis, equivalent to a Bayes' factor = 3.0.[44] The Bayesian models will be evaluated via PP threshold guidelines[44,45] suggesting that PP = 75 to 90%, PP = 91 to 96%, and PP ≥ 97% indicate moderate, strong, and very strong to extreme evidence in favor of the alternative hypothesis, respectively. Data analyses were conducted with R, version 3.5.1.[46] via rstan[47] and brms.[48]



Condition	Finger 1 (Standardized Nicotine [µg/m²])			Finger 2 (Standardized Nicotine [µg/m²])			Finger 3 (Standardized Nicotine [µg/m²])		
	M (SD)	*Mdn (IQR)*	*GeoM*	*M (SD)*	*Mdn (IQR)*	*GeoM*	*M (SD)*	*Mdn (IQR)*	*GeoM*
HW	163.9 (145.0)	127.8 (49.3-233.9)	110.9	56.9 (48.2)	46.5 (19.1-84.7)	37.5	79.6 (56.3)	51.2 (39.6-118.2)	65.5
Sanitization	137.7 (94.2)	127.2 (57.8-183.6)	111.9	169.2 (159.4)	123.0 (60.5-213.3)	117.8	217.0 (106.7)	195.1 (189.5-236.7)	194.7

Fig. 2 Spaghetti plot and table of standardized finger-nicotine levels (g/m²) as a function of handwashing (HW) or sanitization condition over time. Note: The first finger wipe (wipe 1) occurred at minute zero (0) for all participants. The second finger wipe (wipe 2) occurred between 4 and 12 minutes after finger wipe 1. The third finger wipe took place between 40 and 63 minutes after the finger wipe one. The sample sizes for fingers one and two were $n = 7$ for each condition. The sample size for finger-three wipes was $n = 6$ (handwashing) and $n = 5$ (sanitization). GeoM, geometric mean; HW, handwashing; IQR, interquartile range; SD, standard deviation.

Results

Screening, Enrollment, and Sample Characteristics

A total of 14 participants were eligible, consented, and randomized ($n = 7$ HW; $n = 7$ sanitization). See ►Fig. 1 for full study recruitment details. Participants were predominantly Black/African American, female, married or living with a partner, and had a mean age of 38 years (►Table 1). Participants were relatively evenly distributed across infants' mothers, fathers, and other relatives. Participants reported a tendency to smoke 10 or fewer cigarettes/day, and 4 or fewer cigarettes on the day of participation. A majority of participants lived with at least one other person who smoked. Most reported that they never wore gloves when visiting their infant and reported that they tended to wash their hands half the time and sanitize half the time before entering their infant's room. Further, many participants reported visiting often and for extended periods of time during which they held their infants for 60 minutes or longer.

Handwashing/Sanitization Finger-Nicotine Outcomes

►Table 1 reports the unstandardized (raw) finger-nicotine levels and finger-surface-area measurements used to calculate standardized finger-nicotine measurements presented in ►Fig. 2. Standardized finger nicotine was modeled as a function of the interaction between treatment condition and time (in minutes), controlling for respective main effects. ►Fig. 2 provides a spaghetti plot of standardized finger nicotine for each participant and a table of standardized nicotine values across groups. The primary model evaluated change across all three fingers and found an 84.8% posterior probability (PP) that a condition-by-time interaction existed. The interaction was characterized such that change in finger-nicotine levels over time for HW participants was not supported (PP = 59.6%), while a 9.4% finger-nicotine increase (per 10-minute interval) was found for sanitization participants (PP = 91.9%).

We explored transitions between F1 and F2 wipes and F2 and finger three (F3) in two separate models. For the F1–F2 model, a condition-by-time interaction was not supported (PP = 68.6%). However, a main effects -only model found that sanitization participants had nicotine levels 69.2% higher than HW participants (PP = 89.3%) across time. Further, the main effect of time supported that each additional minute between F1 and F2 wipes demonstrated a 6.4% decrease in finger nicotine (PP = 87.8%).

Modeling F2- and F3-nicotine levels also failed to support a condition-by-time interaction (PP = 52.5%). A main effects only model found that sanitization participants had nicotine levels 209.3% higher than HW participants across time (PP = 98.5%), and a main effect of time whereby each 10-minute interval between F2 and F3 wipes led to a 9.0% increase in F3-nicotine levels (PP = 96.8%).

Discussion

It is likely that infants being visited by individuals, who use or live with others who use tobacco/nicotine, may never be fully shielded from THS exposure, as our study (with a rigorous 30-second HW protocol) demonstrated incomplete removal of finger nicotine. HW caused an immediate reduction of finger nicotine; however, similar to a HW study with tobacco harvesters,[30] nicotine remained on skin after washing. Furthermore, after a 40-minute, postwash interval, nicotine levels were similar to baseline (prewash) levels, suggesting that nicotine could be stored in the skin and recontaminate the surface or that participants recontaminate their hands/fingers by touching contaminated surfaces (e.g., clothing). Sanitization appeared to have little impact on finger nicotine. It is possible that applying sanitizer may act as a solvent and distribute finger nicotine elsewhere on the hand through rubbing.

Fully protecting infants in the NICU from THS is challenging for other reasons. THS (e.g., residual nicotine) was detected on a majority of NICU medical staff fingers,[3] despite low personal and household tobacco use, highlighting THS contamination as a widespread societal problem. For example, THS residues are easily detected in rental cars,[49] hotels,[38] multiunit housing complexes,[50] and homes vacated by individuals who smoke (with new nonsmoking occupants),[37,51] making it difficult for parents and NICU staff to completely avoid THS contamination (and transporting it to new environments). Furthermore, research in ICUs has demonstrated that a majority of visitors (i.e., 60%) fail to properly wash their hands prior to entry[52] which is unlikely to change without significant oversight and intervention by hospitals.[53]

As expected, our data show that parents and other family spend significant periods of time visiting and holding their infants which is critical for bonding and infant development but not without potential THS-exposure risks. Many preterm infants have underdeveloped skin,[54] potentiating dermal absorption from nicotine on the hands of caregivers and/or nicotine "off-gassed" from clothing, and we have documented infant exposure to nicotine while hospitalized in the NICU.[5,17]

The current proof-of-concept study underscores the opportunity for significant dermal transfer of nicotine during family visits to infants in NICUs, very low glove use (as a potential barrier), and intermittent HW, with only marginal short-term efficacy for reducing nicotine present on skin. Clinical research demonstrating the potential for health-related harm to children is growing.[27,55–60] For infants cared for or visited by individuals who smoke, limiting THS exposure from caregivers' hands to infants' skin through increased glove use and/or frequent and rigorous HW are potential paths to mitigate this exposure route. Limiting THS exposure may help reduce alterations in the immune system[59] and gut microbiome[27] for preterm and other vulnerable infants and children in hospital settings exposed to nicotine early in life. Future studies with larger samples, different approaches (e.g., measuring nicotine on the entire hand[4,28]), and additional cleaning and barrier methods being evaluated will improve on our methods. Clearly additional research on THS removal is needed to fully protect infants from acute and cumulative THS exposure during high-risk hospitalizations that can last for several months.

Note

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Conflict of Interest

None declared.

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