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Airborne concentrations of volatile organic compounds (VOCs) in hair salons primarily serving women of color

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Abstract

Hairdressers are exposed to volatile organic compounds (VOCs) that can pose health risks. Women of color (Black/Latina) represent nearly one-third of all U.S. hairdressers who may be disproportionally exposed to VOCs through occupational and personal use of hair products and treatments specifically formulated for this demographic. Still, data on workplace VOC exposures in this workforce remains sparse. We conducted area air monitoring of 14 VOCs in three salons serving Black women ("Black salons"), three Dominican salons predominantly serving Latino and Black women and 10 office spaces using active integrated sampling across 8-hour work shifts. Most VOCs measured were detected in hair salons (n = 13) and offices (n = 11). Salons had median VOC concentrations 2-175 times higher than offices. Among salons, 95th percentile VOC concentrations were up to 187 times higher in Black salons than in Dominican salons, suggesting that elevated exposures may occur partly from differences based on product use, services rendered, and salon characteristics (e.g., cleaning practices, ventilation). This is the first study to report indoor air concentrations of multiple individual targeted

VOCs in U.S. hair salons serving women of color, highlighting the need for comprehensive exposure studies and assessment of potential health risks in this understudied and overexposed workforce.

Keywords: Volatile organic compounds (VOCs), salon exposures, hairdressers, Black, Latina, indoor air quality

INTRODUCTION

Hairdressers are exposed to a wide range of volatile organic compounds (VOCs) through their use of VOC-containing hair products when providing salon services (e.g., hair washing, blow-drying, flat ironing, braiding, bleaching and coloring) and/or during chemical treatment of hair with the application of heat[1-3]. Exposure to VOCs may occur through multiple routes including inhalation and dermal absorption[4,5]. Previous studies have shown that select VOCs found in salon products may be linked to adverse health risks, including reproductive[6,7], respiratory[8], and cardiovascular effects[9], as well as cancer[10,11], and dermal and respiratory irritation[12,13]. There are also growing concerns that the use of specialty hair products specifically marketed to women of color, including chemical relaxers, straighteners, and smoothing products (i.e., Brazilian and keratin treatments), may increase women's personal exposures to VOCs[14,15]. Notably, many of these specialty products are reported to contain more hazardous ingredients than those formulated for other demographics[16,17]. It is also reported that women of color use a wider variety of hair and beauty products more frequently than White women[18,19]. Altogether, this suggests that female hairdressers of color may experience an additional chemical burden from occupational exposures when using these products to service their clients. Still, relatively little is known about indoor air quality (IAQ), including indoor air concentrations of VOCs in hair salons predominantly serving populations of color. Moreover, most studies examining VOCs in hair salons have restricted monitoring to less than 8 h, limiting meaningful comparisons with current occupational exposure limits (OELs)[1,12,20-23].

Prior air monitoring studies in salon settings focused on comparing concentrations of only a select number of VOCs to U.S. occupational regulatory standards. For example, McCarthy *et al.* reported that after a single Brazilian blowout or keratin smoothing hair treatment, formaldehyde concentrations in indoor air samples were up to 21 times higher than the U.S. National Institute of Occupational Safety and Health (NIOSH) recommended exposure limit (REL) of 0.016 ppm in seven salons in Oregon[24]. Similarly, Durgam *et al.* reported that hairdressers were exposed to formaldehyde concentrations up to 69 times higher than the NIOSH REL after a single Brazilian blowout treatment in an Ohio salon[25]. In a study of five Taipei salons, Chang *et al.* reported that average airborne formaldehyde concentrations exceeded the NIOSH REL over a five-hour time period and that 18% of air samples collected during this same time period exceeded the Occupational Safety and Health Administration's (OSHA) 8-hour time-weighted average (TWA) action level of 0.5 ppm[1]. This same study also reported that indoor air concentrations of isopropyl alcohol, butyl acetate, and ethyl acetate were elevated in hair salons compared to nearby residential buildings[1]. Collectively, the limited field studies conducted to date suggest that indoor VOC concentrations in hair salons with racially and ethnically diverse workers and clientele may be a source of concern due to the elevated levels and potential exceedance of current regulatory guidelines and standards reported.

Exposure disparities may be prevalent in salon settings, particularly among hairdressers of color who may be overexposed from both occupational and personal use of products specifically marketed to this population[18,19,26]. In the present pilot study, we aimed to address existing knowledge gaps on VOC exposures among hairdressers of color by assessing indoor air exposure to a panel of VOCs in hair salons predominantly serving women of color.

METHODS

Recruitment

Our salon recruitment strategy has been described in detail elsewhere[27-29]. Briefly, we obtained consent from salon owners of six hair salons in the Maryland and Washington D.C. metropolitan area. These salons represent a convenience sample with layouts representative of those commonly found in the area. To be eligible to participate in the study, salon owners had to be ≥ 18 years of age, own a licensed salon, and have ≥ 4 employees working in their salon. Salon owners also had to agree to allow study staff access to the salon to conduct all study protocols. We recruited three Dominican salons (referred to as D01, D02, D03), which served a primarily Latinx clientele and provided a "Dominican blowout" as part of their services. The "Dominican blowout" includes hair washing, setting hair in rollers, then blow-drying and, at the client's request, flat ironing hair. The Dominican blowout is a multi-step process requiring several hair products such as shampoo, conditioning treatments, hair spray, and styling aids to achieve each stage of the hairstyle. We also recruited three salons (referred to as A01, A02, A03 or Black salons) primarily serving Black women. Black salons provided additional services that cater to their main clientele, including applying hair extensions/weaves, chemical relaxing and texturizing, braiding, and sister locs, among other hair services and treatments common among clientele seeking services in these salons.

We also recruited a comparison group of 17 office workers whose ten administrative office spaces in a university setting were monitored (referred to as C01, C02, C03, *etc.*). All study protocols were reviewed and approved by the University of Maryland Institutional Review Board and written informed consent was obtained from salon owners.

Data collection

Data collection in hair salons and office spaces occurred between December 2018 and July 2019. We visited each salon over a four-day period. During the initial visit (i.e., day 1 of the 4-day visit period), trained bilingual/bicultural study staff met with the hair salon owners to determine optimal locations for air monitors [Supplementary Figure 1]. This optimal location was based on ensuring that the air monitoring equipment properly captured routine exposures within the salon while minimally disrupting regular salon activities. Study staff also conducted a walk-through facility inspection at this initial visit to collect data on salon characteristics that could impact indoor salon air quality (e.g., type of furnishing and flooring, windows, presence of live or artificial plants, *etc.*). During this visit, study staff also administered a brief questionnaire to hair salon owners to capture information on additional salon characteristics and behaviors that could influence IAQ and VOC concentrations within the salons, such as the type of ventilation used, hair services provided, and cleaning products used. This questionnaire was administered in either English or Spanish based on the hair salon owner's preference. For offices, study staff conducted site visits in each office over two days. Similar to hair salons, study staff met with office workers during the initial visit to identify the best location for air monitors to minimize disruption of ongoing work activities.

We conducted indoor air monitoring for VOCs in each of the six salons over the course of two consecutive days (i.e., two 8-hour work shift samples) within the same week of a salon's initial visit. The fourth day was dedicated to activities related to biomonitoring of chemical exposures among these hairdressers, as reported elsewhere[27,28,30]. To capture exposure variability and potential high-end exposures, we based the selection of air monitoring days on the salon owners' knowledge of which days their individual salons typically experienced the greatest number of clients. Each salon had two air monitoring stations, where we placed equipment on each air monitoring day to capture the spatial variability of VOC concentrations within salons. These two selected locations were typically at different salon areas, with each location being near hairdresser workstations. Due to limited resources, the air sampling protocol for each of the ten office spaces consisted of only one 8-hour work shift and one sample location within each office space based on the smaller size of the office spaces.

Air sampling

We based our air sampling protocols on those employed in a prior hair salon study[31]. Briefly, an active sampling pump (SKC AirChek® XR5000, SKC Inc., Eighty-Four, PA) was attached to a low flow adapter and connected to an activated charcoal sorbent tube (SKC Inc., Cat. No. 226-01). We set sampling flow rates at 500 $mL \cdot min^{-1}$ and conducted pre- and post-calibration on each sampling day using an electronic calibrator (model 520, Bios Defender, Mesalabs, Lakewood, CO). The sampling flow rate was selected to maximize the detection of compounds in the absence of preliminary data on expected concentrations for many of the VOCs monitored. We deployed each sampler for 8 h at a sampling height within the workers' breathing zone (~1.5 m). Field blanks were collected at each sampling site for each day as part of our quality control protocols by opening the sorbent tubes in the field and capping them immediately without attaching them to a pump.

For each of the six hair salons, we collected area samples using 10 sorbent tubes, including 2 blanks (one blank per day of monitoring at the salon) and 8 air samples (four daily in each salon over the two sampling days; one sample and its duplicate at each of the two sampling locations). Due to equipment malfunction, we sampled only one location on the second day of monitoring for one salon (A02). We also monitored another salon (A03) in only one location over both sampling days for quality control purposes to assess instrument precision. In total, we collected 42 air samples and 12 blanks across all hair salons. Except for one office space (C06), we collected 3 air samples (2 office air samples and 1 blank) for each office space. For one office (C06), we conducted sampling for two days due to monitoring scheduling conflicts, resulting in 6 samples (4 office air samples and 2 blanks). In total, we collected 22 air samples and 11 blanks across the 10 office spaces monitored. All samples and blanks were transported in coolers to the lab at the end of the work shift and were immediately stored at -80 °C until laboratory analyses.

We collected IAQ parameters [i.e., Carbon dioxide (CO_2), relative humidity, temperature] using an AirVisual Pro (IQAir, USA), a low-cost real-time direct reading instrument, in each salon and office during each 8-hour work shift. The AirVisual Pro was calibrated as described before by co-locating with a filter-based sampler[32]. We also measured air velocity in feet per minute (fpm) for each salon and office space at least once daily using an anemometer (DAVIS LCA6000, DAVIS instrument). We measured the air velocity through a three-inch opening at the entrance door and subsequently calculated the ventilation flow rate (Q) in cubic feet per minute (cfm) for each salon and office space according to the following formula: Q = surface area (ft^2) * air velocity ($ft \cdot min^{-1}$). We then calculated air changes per hour or ACH (ACH = Q/V * 60 min; Q = ventilation flow rate in cfm and V = volume of air in the room in ft^3). We measured the dimensions of each workspace in feet (ft) on one of our sampling days to facilitate our calculations.

Laboratory analysis

We quantified a total of 14 VOCs: 1,1-dichloroethane, 1,2-dichloroethane, acetone, benzene, chloroform, ethylbenzene, isopropyl alcohol, methyl chloroform, methylene chloride, n-butyl acetate, tetrachloroethylene, toluene, m-, p-xylene, and o-xylene in air samples using NIOSH method 1501[33]. Selection of these VOCs was based on information in the published literature on what VOCs may potentially be present in indoor salon settings and knowledge of hair product ingredients used in salons [Table 1][1,34-57], as well as the availability of validated laboratory methods. Limits of detection ranged between 0.01 and 46 ppb.

Table 1. Potential sources of exposure to VOCs measured in our study

VOC	CAS#	Potential sources of exposure in hair salons, through products used and/or services provided	Other common sources of exposure outside of hair salon settings
1,1-dichloroethane	75-34-3	N/A[a] - used in cosmetics, but no details provided on actual products[34]	Plastic wrap, adhesives, synthetic fibers, solvent for paints and degreasers, flame retardant coatings for fiber and carpet backings and in piping, coating for steel pipes[34,35]
1,2-dichloroethane	107-06-2	Nail lacquer[34]	Adhesives, cosmetics, pharmaceuticals, varnishes, furniture and automobile upholstery, plastics and vinyl products, including (PVC) pipes[34]
Acetone	67-64-1	Hairspray, nail polish remover, nail polish[36,37]	Particle board, detergents and cleansers, liquid waxes/polish, paint removers[38]
Benzene	71-43-2	Hair styling cream[39]	Tobacco smoke, exhaust from motor vehicles, automobile service stations, industrial emissions, dishwasher liquid detergent, laundry soap[40,41]
Chloroform	67-66-3	Hair dyes and potential impurity in cosmetic products[34]	Adhesive and binding agents, home cleaners, laundry detergents, soaps, degreasers, spot removers, paint removers, graffiti removers and tattoo ink[34,42]
Ethylbenzene	100-41-4	Eyeliner, mascara, foundation, sunscreens, moisturizer with SPF, baby shampoo, nail polish, eyelash glue, hair wigs and extensions, shampoo and hair styling aids[3,36,37]	Tobacco smoke, vehicle exhaust, building materials, manufacturing, foods and beverages, foods packaged in polystyrene containers, liquid hand soap[40,41,43-45]
Isopropyl alcohol	67-63-0	Holding sprays, hair gels, hair mousse, styling sprays, conditioner, shampoos, styling aids, setting lotion, hair color, hair bleach, hair detangler, hair styling aids, foundation, mascara, nail polish, nail glue, nail polish remover[20,34,37,40,46]	Detergents, soap, household cleaners[34]
Methyl chloroform	71-55-6	Hairsprays[47,48]	Household cleaners, glues, aerosol sprays, metal degreasers, paints and contaminated drinking water[34,40,49]
Methylene chloride	75-09-2	Hairspray, hair dye, shampoo, conditioner and hair styling lotions[50-52]	Paint stripper, varnish remover, aerosol spray, degreaser, foam blowing agent and floor cleaners[34,40,53]
n-butyl acetate	123-86-4	Nail polish, nail polish remover, nail glue, wig glue, hairpiece bonding[34,36,37,46]	Tobacco smoke, tile caulk, artificial leather, plastics, lacquers and floor stains[34,40]
Tetrachloroethylene	127-18-4	N/A[a]	Dry cleaning solvent, degreasing solvent, metal drying agents[34,54]
Toluene	108-88-3	Nail glue, hair dyes, wig glue/hairpiece bonding, hairsprays, hair wigs and extensions, hair bleach, hair styling aids, detangler, foundation, mascara, lip gloss[3,36,37]	Tobacco smoke, dyes, fossil fuels, industrial solvents, paints, paint thinners, liquid hand soap[40,41,43,45]
m-, p-xylene	179601-23-1	Shampoos, conditioners, hair treatment/serums, nail polish, and facial cleanser[37]	Tobacco smoke, cleaning agents, body wash, liquid hand soap, gasoline, paint, paint thinners and removers, automobile exhaust, varnish, lacquers, rust preventives, dyes, insecticides, wood finish and floor stains[34,40,55]
o-xylene	95-47-6		

[a]Not applicable; chemical was measured as part of the laboratory panel and no information was available on its actual use in cosmetics and beauty products. VOCs: Volatile organic compounds.

We quantified VOCs using a Trace GC-Ultra gas chromatograph attached to an ISQ Mass Spectrometer (GC-MS) (Thermo Scientific, U.S.). A column, Rtx-VMS, with 30 m length × 0.25 mm internal diameter × 1.40 μm film thickness (Cat# 19915), was used for the analysis. The oven temperature gradient to achieve separation of the analytes was set at an initial temperature of 35 °C with a 1-minute hold; the temperature rate was increased to 5 °C·min^{-1} to reach 100 °C; the final temperature ramp was set to reach 230 °C at a rate of 80 °C·min^{-1}. For analysis of integrated VOC sorbent tubes, we ran calibration curves in each batch by spiking carbon disulfide with a reagent-grade mix of analytes from AccuStandard (P/N# S-78812-5X) at 100, 10, 5, 1, 0.5, 0.1, and 0.05 μg·mL^{-1}. We prepared the lowest standard, 0.05 μg·mL^{-1}, five times and injected it into the GC/MS to calculate the limit of detection (LOD) of each VOC by multiplying the standard deviation by 3. We also subjected field blanks to the entire analytical protocol and treated them blindly as regular samples. We corrected all values using the averaged blank concentration.

Statistical analysis

We first summarized characteristics for each of the six hair salons and 10 office spaces, including the size of the space (ft^2) and IAQ parameters [i.e., CO_2 (ppm), temperature (°C), relative humidity (%), and ventilation flow rate (cfm)]. We also calculated descriptive statistics to characterize indoor ambient VOC concentrations (ppb) for each hair salon and office space monitored, including detection frequencies (DFs), percent breakthrough (%), and distribution of concentrations (p25, p50, p75, maximum) (ppb) observed. VOC concentrations were frequently either left-censored (i.e., concentrations were < LOD for the chemical), or right-censored (i.e., concentrations were above some breakthrough value, BV). As such, excepting tetrachloroethylene and 1,1-dichloroethane for which data was insufficient, we used a maximum likelihood estimation (MLE) method to estimate summary descriptive statistics [e.g., geometric mean (GM), geometric standard deviations (GSD), and relevant percentiles of the lognormal distribution]. As shown in previous studies, the MLE method is suitable for moderately sized data sets with up to 80% censoring for lognormal distributions with small variability (GSD = 2-3)[58]. Briefly, in the MLE method, exposure data are log-transformed where $\mu = \ln(GM)$ and $\sigma = \ln(GSD)$. The ML estimates are values of μ and σ that maximize the likelihood function.

$$\text{Likelihood function}\left(x_1, .. x_n, x_{n+1}, ... x_{n+m}, x_{n+m+1}, .. x_{n+m+b}, |\mu, \sigma\right) = \prod_{i=1}^{n} \text{PDF}(x_i, \mu, \sigma) \prod_{i=n+1}^{n+m} \text{CDF}(\text{LOD}_i, \mu, \sigma) \prod_{i=n+m+1}^{n+m+b} (1 - \text{CDF}(\text{BV}_i, \mu, \sigma))$$

where n = number of detectable measurements, m = number of measurements below the LOD, b = number of measurements above the breakthrough value (BV), x_i values = detectable measurements, LOD_i values = detection limits, PDF = normal probability density function, and CDF = normal cumulative distribution function. This was implemented as an Excel spreadsheet using its built-in optimization algorithm. The GM and GSD estimated values were used to calculate specific percentile values. We calculated 8-hour VOC TWAs and reported percentile values for VOCs frequently detected (i.e., detection frequency, DF > 50%). For VOCs where we experienced breakthrough (i.e., the concentration in the back section of the sorbent tube was > 25% of that observed in the front section), we report breakthrough concentrations, a semi-quantitative result to be interpreted as a concentration that is greater than the sum of the front and back sections of the sorbent tube.

We compared percentiles and maximum VOC concentrations to available OELs. We also used mixed-effects models to calculate the intraclass correlation coefficients (ICC) for VOC concentrations to assess the within and between variability across salons and offices. We restricted these analyses to frequently detected VOCs (DF > 50%). We used the Wilcoxon Mann-Whitney test to examine differences in VOC concentrations between hair salons and office spaces. VOC measurements were averaged to generate a single average value for each facility for the Mann-Whitney test, as this test assumes independent observations and measures within each salon are not independent. For comparisons of VOC concentrations between Black and Dominican hair salons, we relied on qualitative comparisons of descriptive summaries and boxplots rather than statistical tests, given the small sample size. We set statistical significance criteria at $P < 0.05$ for all analyses. All statistical analyses and figures were conducted in Stata 15.0 (Stata Corp, College Station, TX) and GraphPad Prism 9 Software (San Diego, CA), respectively.

Table 2. Characteristics of hair salons (*n* = 6) and office spaces (*n* = 10) monitored

		Number of sorbent tubes collected (No. of blanks)	Salon size (ft^2)	Total number of salon workers employed in the salon	Average # of clients reported on busy days	Indoor air quality parameters				
						CO_2 median (range) (ppm)	Temperature median (range) (°C)	Relative humidity median (range) (%)	Measured CFM per person	ACH
Salons										
Salon ID[a]	A01	8 (2)	1,250	7	20-25	1,080 (680, 1,540)	25.3 (23.4, 29.1)	40 (28, 56)	1.7	0.3
	A02	6[b] (2)	1,890	5	10-15	740 (540, 1,090	23.1 (21.7, 24.3)	40 (31, 56)	0.2	< 0.1
	A03	4[b] (2)	1,250	4	15-25	1,030 (630, 1,240)	23.1 (20.1, 25.2)	50 (47, 53)	0.4	0.1
	D01	8 (2)	1,000	4	15-20	670 (470, 1,110)	23.6 (16.3, 28.6)	32 (18, 55)	1.6	0.2
	D02	8 (2)	1,260	13	NA[d]	880 (580, 1,220)	23.3 (20.6, 24.0)	35 (23, 46)	0.6	0.1
	D03	8 (2)	590	4	18-20	890 (520, 1,470)	22.2 (19.9, 25.3)	42 (26, 51)	1.1	0.2
Offices										
Office space ID	C01	2 (1)	220			930 (680, 1,360)	23.2 (22.6, 23.8)	53 (52, 61)	4.0	0.4
	C02	2 (1)	120			780 (640, 890)	24.4 (23.1, 24.7)	50 (49, 56)	20.0	2.0
	C03	2 (1)	120			880 (700, 990)	24.5 (23.2, 25.4)	47 (43, 54)	2.4	0.2
	C04	2 (1)	190			650 (530, 1,070)	21.5 (20.4, 21.9)	41 (39, 47)	8.9	0.9
	C05	2 (1)	Hallway (NA)[c]			910 (350, 1,460)	21.1 (19.9, 21.7)	52 (51, 56)	Hallway (NA)[c]	Hallway (NA)[c]
	C06	4 (2)	Hallway (NA)[c]			720 (580, 860)	22.3 (22.1, 22.7)	57 (53, 60)	Hallway (NA)[c]	Hallway (NA)[c]
	C07	2 (1)	130			500 (450, 550)	22.5 (20.6, 22.9)	57 (55, 66)	5.3	0.5
	C08	2 (1)	80			530 (490, 900)	24.3 (23.0, 24.6)	47 (44, 56)	7.5	0.8
	C09	2 (1)	120			590 (530, 640)	23.9 (22.6, 24.8)	55 (53, 59)	12.8	1.3
	C10	2 (1)	100			590 (520, 1,200)	23.2 (21.4, 24.5)	49 (47, 57)	6.9	0.7

[a]Notation for salons- Black salons: A01, A02, A03; Dominican salons: D01, D02, D03. [b]Equipment malfunction on the second monitoring day led to a decreased number of sorbent tubes collected. [c]Information was not available for this office space. Hallway denotes a common area to adjacent office spaces of two participants; limited resources prevented us from taking samples from each office space. ft^2: Square feet; CO_2: carbon dioxide; CFM: cubic feet per minute (this refers to the ventilation flow rate in salons and office spaces); ACH: air exchanges per hour.

RESULTS

Hair salon and office characteristics

The indoor environmental characteristics of all six monitored hair salons are presented in Table 2. Briefly, indoor hair salon area dimensions ranged between 590 and 1,890 ft^2. All but one salon (D02) employed < 10 hairdressers, while the number of clients seen on busy days during the workweek typically ranged between 10 and 25 clients. Median CO_2 levels inside salons ranged from 670 to 1,080 ppm. Indoor CO_2 levels were slightly higher (albeit not statistically significant) in Black compared to Dominican salons (mean: 960 *vs.* 830 ppm, respectively). The median temperature ranged from 22.2 to 25.3 °C, while the median relative humidity ranged between 32% and 50% across salons. Ventilation rates ranged from 0.2 to1.7 cfm/person per 1,000 ft^2 (<0.1-0.3 ACH) across salons, which is below the American Society of Heating, Refrigerating and Air-Conditioning Engineers' (ASHRAE) guideline for acceptable indoor air quality in beauty salons of 20 cfm/person per 1,000 ft^2 based on a standard occupant density of 25 persons[59].

The layout configuration for salon A01 entailed partitioned rooms, each used as a hairstylist workstation, and a main reception area, while all other salons had an open concept layout (i.e., no physical partitions between workstations; Table 3). Only one hair salon (D02) additionally provided nail services. All salons had central air for dilution, heating, and cooling, while salons A01, A02 and D02 occasionally used floor fans to supplement the central air, and no salons had operable windows that could be used for natural ventilation nor a local exhaust ventilation system. Salon owners for three of the salons (A02, A03, D03) reported using cleaning products daily, while the others reported using them 1 to 2 days per week (A01, D01, D02) [Table 3]. All salon owners reported frequent use of some form of fragrance-enhancing odorant, including aerosol sprays, scented candles, and electrical outlet plug-in fresheners in salons. While all salon owners indicated that they used hair products made and sold in the U.S., two Dominican salons (D01, D03) indicated they also purchased specialty hair products produced outside the U.S. from local vendors and beauty supply shops originating from Europe, the Caribbean, and South America. Two salon owners (A03 and D03) reported concerns about the air quality in their salons while providing chemically intensive services to clients (Table 3; e.g., hair bleaching and chemical relaxer). Salon owners also reported that no cigarette smoking was allowed indoors.

Area dimensions of office spaces ranged from 80 to 220 ft^2, indoor median CO_2 levels ranged from 500 to 930 ppm, median room temperatures ranged from 21.1 to 24.5 °C, and median relative humidity ranged between 41% and 57%. Ventilation rates across offices ranged from 2.4 to 20.0 cfm/person per 1,000 ft^2 (0.2-2.0 ACH) and generally met the ASHRAE guideline for acceptable indoor air quality of 5 cfm/person per 1,000 ft^2 based on a standard occupant density of 17 persons for office spaces[59].

VOC concentrations: hair salons *vs.* office spaces

VOCs were generally detected more frequently in hair salons than in office spaces. Methylene chloride was the only VOC not detected in the salons sampled, while chloroform, methylene chloride, and tetrachloroethylene were not detected in any office spaces monitored [Table 4]. In salons, acetone and isopropyl alcohol were detected in all samples, while 1,1-dichloroethane, 1,2-dichloroethane, and tetrachloroethylene were detected in < 50% of samples. We observed sample breakthrough for four VOCs (acetone, isopropyl alcohol, n-butyl acetate, and tetrachloroethylene) in samples from five of the six salons monitored. While the percentage of samples with breakthrough was generally < 10%, breakthrough occurred for acetone for 69% of the samples. In offices, we observed a < 10% breakthrough in samples for four VOCs (1,1-dichloroethane, ethylbenzene, m-, p-xylene, and o-xylene).

Median VOC concentrations in hair salons were 2.2 to 175 times higher than in office spaces [Table 4]. Median concentrations of isopropyl alcohol and n-butyl acetate were 175 and 165 times higher within salons than in office spaces, respectively. Similarly, high-end concentrations (i.e., concentrations ≥ 95th percentile) of all VOCs were higher (3-53 times) within salons than in the office spaces monitored. Indoor VOC air concentrations were significantly higher in salons than in office spaces (P-value ≤ 0.002) for

Table 3. Hair salon characteristics based on responses from the hair salon owner survey

Questions	Salons					
	A01	**A02**	**A03**	**D01**	**D02**	**D03**
What type of ventilation system is used in the salon?	Central air and floor fans are used occasionally	Central air, ceiling fans, floor fans	Central air	Central air with a special smoke detection system incorporated	Central air, ceiling fans	Central air
How often are air filters changed?	Yearly	Yearly	Infrequently changed by the building owner	2-3 months	Monthly	2-3 months
How often is your ventilation system checked by a professional?	Every 6 months	Every 6 months	Once a year	Every 2-3 months	Every 6 months	Every 6 months
During business hours, is any smoking allowed inside the salon? (may include cigarettes, cigars, e-cigarettes or any other smoking device)	No	Yes (vaping)	No	No	No	No
In the last 6 months, have there been any renovations done in the salon? This includes renovations such as installing or fixing floors, painting, installing new floors or carpets, *etc.*? How long ago were these renovations done?	No	No	No	Yes (new floor, painting) 1 month prior to sampling	Yes (painting) 6 months prior to sampling	No
How often are cleaning products used inside the salon?	1-2 days/week	Everyday	Everyday	1-2 days/week	1-2 days/week	Everyday
What deodorizers do you use in the salon?	Scented candles, plug-ins	Wax melts in the restroom	Aerosol sprays	Scented candles	None	Scented candles, aerosol sprays, plug-ins, floor cleaner
Where do you purchase your products from? If you buy from someone locally, but the products are from another country, please let me know.	U.S. (local stores)	U.S. (local stores)	U.S. (local stores)	U.S., Venezuela, Italy (buy locally from vendor)	U.S. (beauty supply shop)	U.S., Italy, Dominican Republic (buy locally from beauty supply shops)
Do hair stylists ever purchase their own products for clients in the salon?	Yes	N/A[a]	N/A[a]	N/A[a]	N/A[a]	No
Are you willing to purchase different products than the ones you currently use?	yes	N/A[a]	No	Yes	N/A[a]	Yes
Do you know where to get information on the safety of products used in the salon?	yes	N/A[a]	No	Yes	N/A[a]	Yes
Where do you get information on the safety of the products?	N/A[b]	N/A[a]	Internet	Online research	N/A[a]	Online
Are there any concerns that you have regarding the air quality inside the salon?	No	No	Concerns about products and chemicals used	No	No	Yes, on some occasions, there is too much smoke and strong odors when using chemicals
Have you had any complaints from staff or clients about strong odors or complaints about headaches, skin irritations, or any other symptoms when using certain products?	No	No	Yes (when using powdered bleach, color, relaxer, and sprays); each product is still being used	No	No	No

[a]Not applicable because salons are run by an owner who rents out styling workstations to individuals who operate them independently. [b]Not applicable because we did not ask this question in the initial survey version administered to the salon owner.

benzene, isopropyl alcohol, methyl chloroform, n-butyl acetate, and toluene. No OELs were exceeded for VOCs where no sample breakthrough occurred [Table 4], e.g., benzene and toluene.

Table 4. Descriptive statistics for 8-hour TWA VOC concentrations (ppb) across hair salons and office spaces

VOC	LOD (ppb)[a]	Salons (*n* = 6 salons, 42 sorbent tubes)					Offices (*n* = 10 spaces, 22 sorbent tubes)					*P*-value[d]	Occupational exposure limits (ppb)	
		DF (%)	Breakthrough (%)	p50 (p25, p75)[b] (ppb)	p95 (ppb)[c]	ICC[b]	DF (%)	Breakthrough (%)	p50 (p25, p75)[b] (ppb)	p95 (ppb)[c]	ICC[b]			
1,1-dichloroethane	0.02-0.04	10	0	-	0.05	-	5	5	-	> 0.03		-	1.0e5	PEL
1,2-dichloroethane	0.22-0.41	7	0	-	0.32	-	14	0	-	1.94		-	2.0e5	PEL
Acetone	0.49-0.93	100	69	153 (66.0, 255)	1,190	0.63	73	0	28.1 (9.90, 79.7)	358	0	**< 0.001**	2.5e5/1.0e6	TLV/PEL
Benzene	0.016-0.031	88	0	0.63 (0.20, 2.01)	10.6	0.56	73	0	0.07 (0.02, 0.20)	1.00	0	**0.001**	5.0e2/1.0e3	TLV/PEL
Chloroform	1.74-3.32	55	0	2.35 (< LOD, 3.81)	7.68	0.44	0	0	-	-		-	5.0e4	PEL
Ethylbenzene	0.051-0.097	86	0	0.60 (0.19, 1.89)	9.85	0.76	82	9	0.18 (0.07, 0.45)	1.75	0.46	**0.166**	2.0e4/1.0e5	TLV/PEL
Isopropyl alcohol	0.35-0.67	100	7	664 (310, 1,420)	4,260	0.28	82	0	3.80 (1.08, 13.3)	81.2	0	**< 0.001**	2.0e5/4.0e5	TLV/PEL
Methyl chloroform	0.07-0.13	93	0	0.98 (0.29, 3.32)	19.3	0.48	36	0	-	0.28		**< 0.001**	3.5e5	PEL
Methylene chloride	24.0-46.0	0	-	-	-	-	0	0	-	-		-	5.0e5	PEL
n-butyl acetate	0.01-0.013	98	2	4.95 (1.38, 17.7)	112	0.54	64	0	0.03 (< LOD, 0.18)	2.58	0.48	**< 0.001**	1.5e5	PEL
Tetrachloroethylene	0.31-0.61	10	10	-	> 0.31	-	0	0	-	-		-	1.0e5	PEL
Toluene	0.013-0.024	91	0	2.30 (0.38, 13.9)	185	0.91	82	0	0.17 (0.04, 0.68)	5.08	0	**0.002**	3.0e5	PEL
m-, p-xylene	0.086-0.16	83	0	0.92 (0.27, 3.12)	18.1	0.77	82	9	0.36 (0.13, 0.97)	4.06	0.47	0.291	1.0e5	PEL
o-xylene	0.031-0.60	86	0	0.53 (0.15, 1.86)	11.5	0.79	82	9	0.24 (0.08, 0.76)	4.05	0.43	0.468	1.0e5	PEL

[a]LODs were reported as a range of values because samples were analyzed in batches. [b]Percentile (p25, p50, p75) and ICC values were only reported when > 50% of air samples had detectable levels of target VOC. [c]Percentile values and p95 for chemicals with breakthrough were calculated using MLE except for tetrachloroethylene and 1,1-dichloroethane, for which not enough data were available. [d]*P*-values based on Wilcoxon-Mann-Whitney Test for differences in VOC concentrations between hair salons and office spaces. > #: Maximum concentrations are likely higher based on evidence of sample breakthrough; the value reported reflects the upper LOD concentration. Significant findings are listed in boldface (*P*-value < 0.05). TWA: Time-weighted average; VOC: volatile organic compound; LOD: limit of detection; % DF: percent detection frequency; p#: percentiles; ICC: intraclass correlation; PEL: permissible exposure level published by OSHA (OSHA: Occupational Safety and Health Administration); TLV: threshold limit value published by ACGIH (ACGIH: American Conference of Governmental Industrial Hygienists); MLE: maximum likelihood estimates.

ICC values among salons and office spaces for repeated samples for frequently detected VOCs ranged from 0 to 0.91 [Table 4]. Specifically, ICC values for samples across salons ranged from 0.28 to 0.91, indicating that 9%-72% of the variability in VOC concentrations across salons was due to variability in concentrations within salons. Of note, ICC values for ethylbenzene, toluene, m-, p-xylene and o-xylene were 0.76, 0.91, 0.77, and 0.79, respectively, indicating that the number of samples obtained was adequate to characterize exposures during the sampling period. Conversely, ICC values for acetone, benzene, chloroform, isopropyl alcohol, methyl chloroform, and n-butyl acetate ranged from 0.28 to 0.63, indicating poor to moderate reproducibility, suggesting the need for more samples to adequately characterize exposure to these VOCs within salons over similar sampling periods. For office spaces, we generally observed greater within- than between-office variability in VOC concentrations; ICC values ranged between 0 and 0.48, indicating that 52%-100% of the variability in VOC measurements in offices was due to intra-office variability.

VOC concentrations: Black *vs.* Dominican salons

Acetone and isopropyl alcohol were detected in all salons [Supplementary Figure 2, Table 4], with concentrations ranging between 0.49 to > 1,190 ppb and 0.35 to > 4,260 ppb, respectively. While median concentrations for all VOCs were higher in Dominican salons than in Black salons, high-end concentrations (i.e., ≥ 95th percentile) for 8 out of 10 frequently detected VOCs were 2 to 187 times higher in Black salons compared to Dominican salons [Figure 1, Table 5].

ICC values for VOC concentrations across Black salons ranged from 0.26 to 0.90 and 0.04 to 0.97 in Dominican salons [Table 5]. These ranges indicate that 10%-74% and 3%-96% of the variability in VOC concentrations across Black and Dominican salons, respectively, were due to within-salon variability. ICC values for select VOCs, including acetone, benzene, isopropyl alcohol, methyl chloroform, and n-butyl acetate, ranged from 0.04 to 0.71 across both salon types, reflecting poor to moderate reproducibility over the sampling period.

DISCUSSION

In the present study, we characterized airborne concentrations of 14 VOCs in six salons and 10 office spaces predominantly occupied by women of color (Black/Latina). We detected 13 VOCs within hair salons at consistently higher concentrations than in office spaces. We also found that while median concentrations of most measured VOCs were similar among Black and Dominican salons, high-end exposures were consistently higher in Black salons, which suggests that differences in salon-level characteristics such as the products used or services provided may, in part, influence workplace exposures [Supplementary Figure 3].

Consistent with other studies conducted outside the U.S. that assessed some of the same VOCs using similar sampling methods (acetone, benzene, ethylbenzene, isopropyl alcohol, n-butyl acetate, toluene, and xylene), we found that airborne exposures of VOCs for which we did not experience breakthrough (benzene, ethylbenzene, toluene and xylene) to be below current OELs (i.e., current OSHA PELs, NIOSH RELs, ACGIH TLVs) [Table 6][1,12,20-23,31,56,60]. Due to the breakthrough observed, we cannot confirm that airborne concentrations of acetone, isopropyl alcohol, n-butyl acetate, or tetrachloroethylene in these salons were below current OELs because breakthrough leads to underestimation of target contaminants of concern[61]. Additionally, the lack of OEL exceedance to select VOCs in our study should not be construed as the absence of any health risks[62-64]. Biomonitoring results from our previously published work in this study population demonstrated that hairdressers working in the salons we monitored were exposed to many more VOCs and other chemicals of concern, and generally at disparately higher concentrations than females in the U.S. general population[27,28] as reported in the National Health and Nutrition Examination Survey (NHANES) (2015-2016). It is also important to note that OELs have limitations, including the fact that they may not be protective of workers during vulnerable periods such as the preconception or prenatal period. For example, there is some evidence to suggest that VOCs like benzene, ethylbenzene, and toluene are reproductive and developmental toxicants posing a potential risk to hairdressers during these sensitive periods[65]; however, current OELs for these VOCs are based on acceptable risks derived from limited

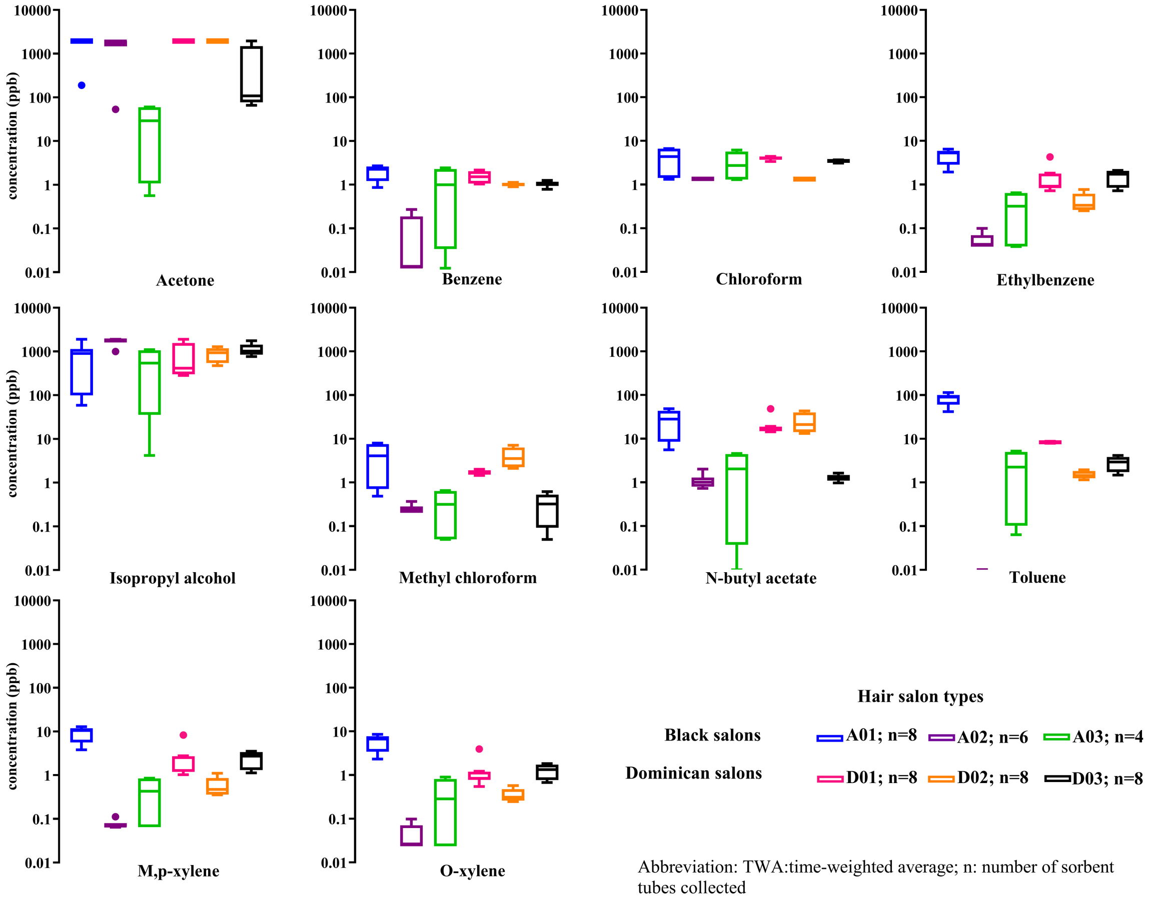

Figure 1. 8-hour TWA concentrations for frequently detected VOCs across individual salons (ppb). TWA: Time-weighted average; VOCs: volatile organic compounds.

toxicological data rather than just developmental and reproductive toxicity[66,67]. Moreover, OELs may not protect workers with pre-existing chronic conditions such as asthma and do not account for the potential effects that may arise from chemical mixtures[66-68].

Several studies have conducted stationary air monitoring of VOCs in hair salons using integrated air measurements [Table 6]. However, only three studies conducted in Taiwan, Greece, and Canada have quantified VOCs in salons for at least eight hours, allowing for comparisons with our study[31,56,60]. Comparison of the same VOCs measured in each of these studies and ours showed that the average ethylbenzene concentration in the salons from our study was one order of magnitude lower than was reported among Taiwan-based salons in 2019[60]. Similarly, the average toluene concentration in our study was up to one order of magnitude lower than those reported in salons in the Taiwan study and in Canada between 1996 and 1997[56,60]. Conversely, the average toluene and acetone concentrations from our study were up to two orders of magnitude higher than levels reported in a 2009 study in Greece[31]. Finally, the average acetone concentration from our study was at least two orders of magnitude higher than reported in the Taiwan study[60]. Considering that these studies span over 20 years, differences in industry-wide standards related to the type of products used for hair services at different time points and changes in chemical ingredient formulations of products used in salons at various time points could explain, in part, the differences observed across these studies. Differences in building characteristics, such as salon location (e.g., proximity to high-density traffic) and the type of ventilation systems could also explain differences across these studies[1,20]. Moreover, the salons in our study catered primarily to Black or Latina clients, a

Table 5. Descriptive statistics of 8-hour TWA concentrations (ppb) for frequently detected VOCs across Black and Dominican salons[a]

VOC	Black salons (*n* = 3 salons, 18 sorbent tubes)			Dominican salons (*n* = 3, 24 sorbent tubes)			[p50 Black] / [p50 Dominican]	[p95 Black] / [p95 Dominican]	Occupational exposure limits (ppb)	Occupational limit
	ICC	p50 (ppb)	p95 (ppb)	ICC	p50 (ppb)	p95 (ppb)				
Acetone	0.64	127	389	0.71	153	1,190	0.8	0.3	2.5e5/1.0e6	TLV/PEL
Benzene	0.64	0.20	22.9	0.47	1.16	1.79	0.2	13	5.0e2/1.0e3	TLV/PEL
Chloroform	0.26	1.53	11.1	0.97	2.71	5.95	0.6	1.9	5.0e4	PEL
Ethylbenzene	0.85	0.24	31.7	0.34	0.86	2.99	0.3	11	2.0e4/1.0e5	TLV/PEL
Isopropyl alcohol	0.51	575	8,070	0.04	738	1,820	0.8	4.4	2.0e5/4.0e5	TLV/PEL
Methyl chloroform	0.44	0.59	9.90	0.70	1.09	10.0	0.5	1.0	3.5e5	PEL
n-butyl acetate	0.59	2.80	144	0.59	7.46	67.7	0.4	2.1	1.5e5	PEL
Toluene	0.90	1.12	1,980	0.96	3.05	10.6	0.4	187	3.0e5	PEL
m-, p-xylene	0.85	0.31	79.7	0.26	1.29	5.01	0.2	16	1.0e5	PEL
o-xylene	0.83	0.21	55.4	0.30	0.74	2.37	0.3	23	1.0e5	PEL

[a]Table shows only VOCs with > 50% detection across salons. TWA: Time-weighted average; VOCs: volatile organic compounds; ICC: intraclass correlation; p#: represents percentiles; TLV: threshold limit value published by ACGIH (ACGIH: American Conference of Governmental Industrial Hygienists); PEL: permissible exposure level published by OSHA (OSHA: Occupational Safety and Health Administration).

racial/ethnic group different from those served by salons in prior studies. Consequently, the hair products used on clients and the services rendered could be markedly different because clients' hair types and textures can heavily influence business practices and indoor contaminant exposures to both hairdressers and clients. For instance, women of Black descent generally have coarser, thicker hair than White women, which may prompt the use of more products and specialty products such as hair relaxers, which contain ingredients of concern to maintain their hair[16,69]. As a result, differences in the types of products and services provided, along with the frequency of product usage, could explain the differences across studies. We can also not dismiss that our air monitoring was not exhaustive of all potential indoor contaminants in salons. For example, Lothrop *et al.* identified 31 unique VOCs in the indoor air of Latino salons in Arizona[70], so it is still possible that concentrations for VOCs not measured differ from those measured in this study.

We also found that concentrations of select VOCs, including acetone, benzene, isopropyl alcohol, methyl chloroform, and n-butyl acetate during the sampling period, could be potentially influenced more by within- rather than between- salon-level characteristics (ICCs ≤ 0.63). Workplace practices related to cleaning and use of deodorizers within salons could also contribute to differences in VOC exposures within hair salons[5,71]. Hair salon owners for five of the six salons monitored reported frequently using some type of deodorizer in the salon, such as scented candles, aerosol sprays, and plug-in air fresheners (i.e., air fresheners that plug into electrical outlets that typically feature porous polymers that act as wicks; electricity then powers a warmer that heats scented gels or oils in the plug-in to enhance the scent and spread of fragrance). Additionally, the types of products used, types of services rendered and frequency of services provided within the sampled salons, and number of clients serviced may explain, in part, some of this variability. For instance, except for acetone and isopropyl alcohol, whose concentrations were expected to be high due to their frequent use in hair and nail products used in salons[36,37], VOC concentrations in Salon A02 were some of the lowest reported across all salons in this study [Figure 1]. Most hairdressers in this salon reported performing multiple types of "natural hairstyles" (i.e., those that do not chemically alter the

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Table 6. Range of VOC concentrations detected in other hair salon settings and the present study (ppb) based on active air sampling[a,b]

Country	Ref.	# of air samples	# of hours sampled	Sampling flow rate (mL·min^{-1})	Range of VOCs measured in ppb							
					Acetone	Benzene	Ethyl benzene	Isopropyl alcohol	n-butyl acetate	Toluene	m-, p-xylene	o-xylene
The United States	Present study	42	8	500	0.49-1,190	<0.02-10.6	<0.05-9.85	0.35-4,260	0.01-112	<0.01-185	<0.09-18.3	<0.03-11.5
Canada	Labrèche *et al.*[56]	12-101	8	50-100	341-9,350	-	-	16.3-11,700	10.5-318	5.30-2,220	-	-
Cyprus	Kaikiti *et al.*[23]	30	0.17	100		15.7-37.6	13.4-46.5			107-423		12.0-21.9
Greece	Tsigonia *et al.*[31]	3	7-9	600	45.0-96.8	Not detected	-	-	-	0.71-17.8	-	-
Iran	Baghani *et al.*[21]	50	0.83	200	-	<1.57-28.2	1.15-30.4	-	-	<1.33-14.6	-	-
	Hadei *et al.*[12]	60	0.5	200	-	1.48-3.55	1.77-5.09	-	-	1.18-3.71	-	0.72-2.17
Norway	Hollund *et al.*[20]	10	5	100	-	-	-	163-6,020	-	10.1-29.2	-	-
Spain	Ronda *et al.*[22]	28	1.4-3	50	4.21-1,020	0.00-6.26	0.00-40.0	4.07-1,180	-	5.31-82.3	-	0.00-6.91
Taiwan	Chang *et al.*[1]	30	5	50	0.78-109	-	-	5.90-504	0.04-10.3	-	-	-
	Senthong *et al.*[60]	36	8	50	39.2-64.8		20.0-38.8		47.8-113	61.8-109	-	-
ACGIH TLV / OSHA PEL					2.5e5/1.0e6	5.0e2/1.0e3	2.0e4/1.0e5	2.0e5/4.0e5	1.5e5	3.0e5	1.0e5	1.0e5

[a]VOCs were only reported if > 50% of air samples had detectable levels in our study and the VOC was measured by at least one other study. [b]Reported concentrations from our study represent minimum to 95th percentile, while the range was reported for all other studies. Thus, the maximum values from our study are higher than 95th percentile. >: maximum concentrations are higher than the 95th percentiles presented in the table. VOC: Volatile organic compound; ACGIH: American Conference of Governmental Industrial Hygienists; TLV: threshold limit value; OSHA: Occupational Safety and Health Administration; PEL: permissible exposure level.

natural hair texture), such as braiding, and less services considered or perceived to be more chemical-intensive treatments (e.g., hair relaxing, texturizing) compared to other salons in the study [Supplementary Figure 3]. However, hairdressers who provide "natural hairstyles" may still be exposed to high levels of other VOCs and chemicals not measured in the present study as previously demonstrated through biomonitoring among hairdressers working in these salons[27]. Moreover, hairsprays and nail products are a predominant source of acetone in salons [Table 1]. However, only Salon D02 offered nail services, and its acetone concentrations were similar to those of other salons [Figure 1]. Given that acetone levels were significantly lower in offices, these results may suggest that hairsprays are an important source of acetone exposure in these salons. On the other hand, the provision of services by hairdressers perceived as more chemical-intensive, such as chemical hair relaxing, may help explain the elevated levels of other VOCs like toluene and xylene in Salon A01, which reported providing more chemical-intensive services than other salons [Supplementary Figure 3]. These results further support our previously published work that salon-level factors may influence VOC exposures[27].

Our pilot study had some limitations. First, due to resource constraints, we were not able to measure exposures in salons serving a White or mixed clientele, preventing comparisons of exposures for hairdressers using different types of products or providing other services, limiting the generalizability of our findings to salons serving other demographics. Future research should include salons serving a more racially/ethnically diverse clientele to elucidate the relationship between hair product types and services provided and hairdressers' exposures. Additionally, our assessment of temporal trends of VOC concentrations was limited to a two-day sampling period, preventing us from assessing temporal exposure trends over a longer sampling period. Future studies should consider collecting multiple samples across different seasons and time frames to better characterize exposure estimates within salon settings. We also could not evaluate whether the CO_2 levels in our salons were adequate for customer and worker comfort since we did not assess outdoor CO_2 concentrations, as suggested by ASHRAE[72]. Future research should include outdoor air measurements to ascertain its influence on indoor air quality. Because we had sample breakthrough for some VOCs (i.e., acetone, isopropyl alcohol, n-butyl acetate, and tetrachloroethylene), we could not estimate true high-end exposures and were unable to compare them to current OELs. The use of different sampling media and flow rates to assess ambient exposure to a large chemical panel and prevent breakthrough should be considered in future studies. Moreover, future research in salon settings should consider the impact of other indoor activities like vaping on indoor air quality. Although no cigarette smoking was reported in the salons monitored, vaping was observed in one facility (A02) in a large area used as a barbershop that was sectioned off from the hair salon area.

Despite these limitations, our study has several notable strengths. This study is the first to characterize exposures to a panel of VOCs in indoor air within U.S. hair salons employing Black female workers primarily serving a female clientele of color (Black/Latina). Airborne VOCs can help apportion the occupational inhalation exposure burden from exposures due to personal use or other sources of VOCs. Our work expanded on VOC exposure assessment in U.S. hair salons, particularly in Black salons, by capturing the potential range of exposures these hairdressers might experience while working with multiple products widely used in salons throughout the workday. Our results improve our understanding of the potential VOC exposure burden and may be used to help inform future studies examining adverse health risks related to VOC exposures among hairdressers. The exposure information collected in our study is also timely due to rising concerns that products marketed to women of color contain more toxic chemicals, potentially overexposing hairdressers of color serving this demographic[16,69,73]. Our study further demonstrates differences in VOC exposure between Black and Dominican salons, highlighting the need to assess exposure in salons serving diverse clientele to identify factors that could contribute to exposure disparities. We also monitored office spaces, allowing us to compare VOC exposures between our hair salons and an occupational setting expected to have lower exposures to the selected VOCs. Because we collected 8-hour work shift samples and generated 8-hour TWAs, we were also able to assess whether exposures surpassed current U.S. 8-hour occupational exposure guidelines, overcoming a major limitation in prior studies that sampled for shorter periods[1,12,20-22].

CONCLUSION

In summary, this study provides novel insight into the characterization of select VOC exposures among hairdressers of color, informing future studies examining potential occupational health risks. Because of the difficulty in ensuring adequate ventilation in salon settings, some recommendations are to open doors and, if available, windows during the use of products and provision of services known to emit VOCs or be chemically intensive. The use of fans and air purifiers may also help mitigate VOC exposures as their use would increase the air exchange rates, improving indoor ventilation when used according to the manufacturer's guidelines. Reducing product use or limiting services offered could also help mitigate exposures, although this may not be economically feasible based on client demands and for specific hair services until safer alternatives become readily available. Further research is needed to identify other modifiable exposure factors (e.g., use of personal protective equipment and other workplace practices) to safeguard client and worker health, as differences in salon-level factors, including the products used and services offered, may influence chemical exposures. Future research should also assess the barriers and facilitators involved in the modification of exposure reduction behaviors and salon-level practices to improve indoor air quality, given that many salons are in resource-deprived communities and cultural preferences may dictate the services and products offered.

In salon settings, exposure to VOCs and other contaminants of concern, many of which are neurodevelopmental and reproductive toxicants, should not be disregarded, as many female hairdressers are of reproductive age and may work in salons during critical periods including the preconception and prenatal period. This poses potential health risks for both women and children. In fact, close to 50% of hairdressers in the present study reported working in a salon while pregnant. Our findings also underscore the need for manufacturers to produce safer products and the need for further research to identify occupational exposure disparities within salon settings, as 30% of this predominantly female, low-wage workforce are women of color who may already be overburdened by both chemical and non-chemical stressors (e.g., no health insurance, limited or poor healthcare access) internal and external to their occupational environment. This demographic is also overburdened by endocrine-disrupting chemicals from personal care products marketed to this population used both on the job and for personal use, potentially posing adverse health risks. This study represents an essential first step to documenting and understanding the extent of occupational chemical exposures among hairdressers of color who primarily serve women of color - an understudied and potentially overburdened worker group, and highlights the need for further research to ensure worker health and safety.

DECLARATIONS

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Authors' contributions

Involved in data acquisition, data curation, data cleaning, formal analysis, methodology, visualization, writing the original draft, writing-reviewing and editing: Kavi LK

Involved in data cleaning, methodology, writing-reviewing and editing: Shao Y

Involved in methodology, formal analysis, and assisting with writing the initial draft: Ramachandran G

Involved in project administration, writing-reviewing and editing: Louis LM

Involved in project administration and resources: Pool W, Randolph K

Assisted with recruitment: Thomas S

Involved in conceptualization, resources, supervision, writing-reviewing and editing, generation of study instruments, and methodology: Rule AM

Involved in conceptualization; funding and data acquisition; investigation; methodology; project administration; generation of study instruments; resources; supervision of field work, data analysis and data visualization; and assisting with writing the initial draft, reviewing and editing: Quirós-Alcalá L

Availability of data and materials
Not applicable.

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Conflicts of interest
All authors declared that there are no conflicts of interest.

Ethical approval and consent to participate
Not applicable

Consent for publication
Not applicable.

REFERENCES

1. Chang CJ, Cheng SF, Chang PT, Tsai SW. Indoor air quality in hairdressing salons in Taipei. *Indoor Air* 2018;28:173-80. DOI PubMed
2. Pierce JS, Abelmann A, Spicer LJ, et al. Characterization of formaldehyde exposure resulting from the use of four professional hair straightening products. *J Occup Environ Hyg* 2011;8:686-99. DOI PubMed
3. Auguste D, Miller SL. Volatile organic compound emissions from heated synthetic hair: a pilot study. *Environ Health Insights* 2020;14:1178630219890876. DOI PubMed PMC
4. Lind ML, Boman A, Sollenberg J, Johnsson S, Hagelthorn G, Meding B. Occupational dermal exposure to permanent hair dyes among hairdressers. *Ann Occup Hyg* 2005;49:473-80. DOI PubMed
5. Kezic S, Nunez R, Babić Ž, et al. Occupational exposure of hairdressers to airborne hazardous chemicals: a scoping review. *Int J Environ Res Public Health* 2022;19:4176. DOI PubMed PMC
6. Lin CC, Huang CN, Wang JD, et al. Exposure to multiple low-level chemicals in relation to reproductive hormones in premenopausal women involved in liquid crystal display manufacture. *Int J Environ Res Public Health* 2013;10:1406-17. DOI PubMed PMC
7. Cassidy-Bushrow AE, Burmeister C, Birbeck J, et al. Ambient BTEX exposure and mid-pregnancy inflammatory biomarkers in pregnant African American women. *J Reprod Immunol* 2021;145:103305. DOI PubMed PMC
8. Mendes A, Madureira J, Neves P, Carvalhais C, Laffon B, Teixeira JP. Chemical exposure and occupational symptoms among Portuguese hairdressers. *J Toxicol Environ Health A* 2011;74:993-1000. DOI PubMed
9. Ma CM, Lin LY, Chen HW, Huang LC, Li JF, Chuang KJ. Volatile organic compounds exposure and cardiovascular effects in hair salons. *Occup Med* 2010;60:624-30. DOI PubMed
10. Acheson ED, Barnes HR, Gardner MJ, Osmond C, Pannett B, Taylor CP. Formaldehyde process workers and lung cancer. *Lancet* 1984;1:1066-7. DOI PubMed
11. Warden H, Richardson H, Richardson L, Siemiatycki J, Ho V. Associations between occupational exposure to benzene, toluene and xylene and risk of lung cancer in Montréal. *Occup Environ Med* 2018;75:696-702. DOI PubMed
12. Hadei M, Hopke PK, Shahsavani A, et al. Indoor concentrations of VOCs in beauty salons; association with cosmetic practices and health risk assessment. *J Occup Med Toxicol* 2018;13:30. DOI PubMed PMC
13. Choi YH, Kim HJ, Sohn JR, Seo JH. Occupational exposure to VOCs and carbonyl compounds in beauty salons and health risks associated with it in South Korea. *Ecotoxicol Environ Saf* 2023;256:114873. DOI PubMed
14. Aglan MA, Mansour GN. Hair straightening products and the risk of occupational formaldehyde exposure in hairstylists. *Drug Chem Toxicol* 2020;43:488-95. DOI PubMed
15. Occupational Safety and Health Administration. Hair salons - Formaldehyde in your products. Available from: https://www.osha.gov/hair-salons/products. [Last accessed on 2 Jul 2024].
16. James-Todd T, Senie R, Terry MB. Racial/ethnic differences in hormonally-active hair product use: a plausible risk factor for health disparities. *J Immigr Minor Health* 2012;14:506-11. DOI PubMed

17. Adewumi-Gunn T. Promoting safer cosmetics through comprehensive legislation. 2017. Available from: https://escholarship.org/uc/item/9jq5p3pv. [Last accessed on 2 Jul 2024].
18. Dodson RE, Cardona B, Zota AR, Robinson Flint J, Navarro S, Shamasunder B. Personal care product use among diverse women in California: taking stock study. *J Expo Sci Environ Epidemiol* 2021;31:487-502. DOI PubMed
19. Preston EV, Chan M, Nozhenko K, et al. Socioeconomic and racial/ethnic differences in use of endocrine-disrupting chemical-associated personal care product categories among pregnant women. *Environ Res* 2021;198:111212. DOI PubMed PMC
20. Hollund BE, Moen BE. Chemical exposure in hairdresser salons: effect of local exhaust ventilation. *Ann Occup Hyg* 1998;42:277-82. PubMed
21. Baghani AN, Rostami R, Arfaeinia H, Hazrati S, Fazlzadeh M, Delikhoon M. BTEX in indoor air of beauty salons: risk assessment, levels and factors influencing their concentrations. *Ecotoxicol Environ Saf* 2018;159:102-8. DOI PubMed
22. Ronda E, Hollund BE, Moen BE. Airborne exposure to chemical substances in hairdresser salons. *Environ Monit Assess* 2009;153:83-93. DOI PubMed
23. Kaikiti C, Stylianou M, Agapiou A. TD-GC/MS analysis of indoor air pollutants (VOCs, PM) in hair salons. *Chemosphere* 2022;294:133691. DOI PubMed
24. McCarthy K, McLaughlin D, Montgomery D, Munsell P, Schuster M, Wood M. "Keratin-based" hair smoothing products and the presence of formaldehyde. 2010. Available from: https://osha.oregon.gov/OSHAPubs/reports/keratin-based-hair-smoothing-report.pdf. [Last accessed on 2 Jul 2024].
25. Durgam S, Page E. Formaldehyde exposures during Brazilian blowout hair smoothing treatment at a hair salon - Ohio. 2011. Available from: https://www.cdc.gov/niosh/hhe/reports/pdfs/2011-0014-3147.pdf. [Last accessed on 2 Jul 2024].
26. Preston EV, Fruh V, Quinn MR, et al. Endocrine disrupting chemical-associated hair product use during pregnancy and gestational age at delivery: a pilot study. *Environ Health* 2021;20:86. DOI PubMed PMC
27. Louis LM, Kavi LK, Boyle M, et al. Biomonitoring of volatile organic compounds (VOCs) among hairdressers in salons primarily serving women of color: a pilot study. *Environ Int* 2021;154:106655. DOI PubMed PMC
28. Boyle MD, Kavi LK, Louis LM, et al. Occupational exposures to phthalates among Black and Latina U.S. hairdressers serving an ethnically diverse clientele: a pilot study. *Environ Sci Technol* 2021;55:8128-38. DOI PubMed
29. Shao Y, Kavi L, Boyle M, et al. Real-time air monitoring of occupational exposures to particulate matter among hairdressers in Maryland: a pilot study. *Indoor Air* 2021;31:1144-53. DOI PubMed
30. Newmeyer MN, Quirós-Alcalá L, Kavi LK, Louis LM, Prasse C. Implementing a suspect screening method to assess occupational chemical exposures among US-based hairdressers serving an ethnically diverse clientele: a pilot study. *J Expo Sci Environ Epidemiol* 2023;33:566-74. DOI PubMed PMC
31. Tsigonia A, Lagoudi A, Chandrinou S, Linos A, Evlogias N, Alexopoulos EC. Indoor air in beauty salons and occupational health exposure of cosmetologists to chemical substances. *Int J Environ Res Public Health* 2010;7:314-24. DOI PubMed PMC
32. Zamora ML, Rice J, Koehler K. One year evaluation of three low-cost $PM_{2.5}$ monitors. *Atmos Environ* 2020;235:117615. DOI PubMed PMC
33. National Institute of Occupational Safety and Health. Hydrocarbons, aromatic: Method 1501. NIOSH Manual of Analytical Methods (NMAM), 4th edition. 2003. Available from: https://www.cdc.gov/niosh/docs/2003-154/pdfs/1501.pdf. [Last accessed on 2 Jul 2024].
34. National Library of Medicine. PubChem. Available from: https://pubchem.ncbi.nlm.nih.gov/. [Last accessed on 2 Jul 2024].
35. Agency for Toxic Substances and Disease Registry. Toxicological profile for 1,1-Dichloroethane. 2015. Available from: https://wwwn.cdc.gov/TSP/ToxProfiles/ToxProfiles.aspx?id=718&tid=129. [Last accessed on 2 Jul 2024].
36. Women's Voices for the Earth. Beauty and its beast: Unmasking the Impacts of Toxic Chemicals on Salon Workers. 2014. Available from: https://womensvoices.org/wp-content/uploads/2014/11/Beauty-and-Its-Beast.pdf. [Last accessed on 2 Jul 2024].
37. EWG's Skin Deep®. Cosmetics Database. Available from: https://www.ewg.org/skindeep/. [Last accessed on 2 Jul 2024].
38. CDC. NIOSH pocket guide to chemical hazards. Acetone. 2019. Available from: https://www.cdc.gov/niosh/npg/npgd0004.html. [Last accessed on 2 Jul 2024].
39. California Department of Public Health. California Safe Cosmetics Program (CSCP) Product Database. Available from: https://cscpsearch.cdph.ca.gov/search/publicsearch. [Last accessed on 2 Jul 2024].
40. Consumer Product Information Database. What's in it: health effects of consumer products. Available from: https://www.whatsinproducts.com/pages/index/1. [Last accessed on 2 Jul 2024].
41. Agency for Toxic Substances and Disease Registry. ToxFAQs™ for toluene. 2017. Available from: https://wwwn.cdc.gov/TSP/ToxFAQs/ToxFAQsDetails.aspx?faqid=160&toxid=29. [Last accessed on 2 Jul 2024].
42. Agency for Toxic Substances and Disease Registry. Toxicological profile for chloroform. Available from: https://wwwn.cdc.gov/TSP/ToxProfiles/ToxProfiles.aspx?id=53&tid=16. [Last accessed on 2 Jul 2024].
43. Rodgman A, Perfetti TA. The chemical components of tobacco and tobacco smoke. 2nd edition. CRC Press; 2013. DOI
44. National Toxicology Program. 14th report on carcinogens (RoC). Available from: https://www.comfortncolor.com/HTML/NewStyrene/Carcinogens/14th%20Report%20on%20Carcinogens%20(RoC).pdf. [Last accessed on 2 Jul 2024].
45. Boyle EB, Viet SM, Wright DJ, et al. Assessment of exposure to VOCs among pregnant women in the national children's study. *Int J Environ Res Public Health* 2016;13:376. DOI PubMed PMC
46. Cosmetic Ingredient Review. CIR Reports. Available from: https://cir-reports.cir-safety.org/. [Last accessed on 2 Jul 2024].
47. Aviado DM. Methyl chloroform and trichloroethylene in the environment. 1st edition. CRC Press; 2018. DOI

48. CDC. Occupational health guidelines for chemical hazards: methyl chloroform. 1988. Available from: https://www.cdc.gov/niosh/docs/81-123/default.html. [Last accessed on 2 Jul 2024].
49. Methyl chloroform (1,1,1-trichloroethane). 2000. Available from: https://www.epa.gov/sites/production/files/2016-09/documents/methyl-chloroform.pdf. [Last accessed on 2 Jul 2024].
50. U.S. Food & Drug Administration. Import alert 53-06. Available from: https://www.accessdata.fda.gov/cms_ia/importalert_130.html. [Last accessed on 2 Jul 2024].
51. Code of federal regulations. 21 CFR § 700.19 - Use of methylene chloride as an ingredient of cosmetic products. Available from: https://www.law.cornell.edu/cfr/text/21/700.19. [Last accessed on 2 Jul 2024].
52. 3: Final report on the safety assessment of methylene chloride. *J Am Coll Toxicol* 1988;7:741-835. DOI
53. Agency for Toxic Substances and Disease Registry. Toxicological profile for methylene chloride. Available from: https://wwwn.cdc.gov/TSP/ToxProfiles/ToxProfiles.aspx?id=234&tid=42. [Last accessed on 2 Jul 2024].
54. Agency for Toxic Substances and Disease Registry. Toxicological profile for tetrachloroethylene (PERC). Available from: https://wwwn.cdc.gov/TSP/ToxProfiles/ToxProfiles.aspx?id=265&tid=48. [Last accessed on 2 Jul 2024].
55. Agency for Toxic Substances and Disease Registry. Toxicological profile for xylene. Available from: https://wwwn.cdc.gov/TSP/ToxProfiles/ToxProfiles.aspx?id=296&tid=53. [Last accessed on 2 Jul 2024].
56. Labrèche F, Forest J, Trottier M, Lalonde M, Simard R. Characterization of chemical exposures in hairdressing salons. *Appl Occup Environ Hyg* 2003;18:1014-21. DOI PubMed
57. de Gennaro G, de Gennaro L, Mazzone A, Porcelli F, Tutino M. Indoor air quality in hair salons: screening of volatile organic compounds and indicators based on health risk assessment. *Atmospheric Environment* 2014;83:119-26. DOI
58. Huynh T, Ramachandran G, Banerjee S, et al. Comparison of methods for analyzing left-censored occupational exposure data. *Ann Occup Hyg* 2014;58:1126-42. DOI PubMed PMC
59. ASHRAE. ANSI/ASHRAE addendum p to ANSI/ASHRAE standard 62.1-2013. Ventilation for acceptable indoor air quality. 2015. Available from: https://www.ashrae.org/file%20library/technical%20resources/standards%20and%20guidelines/standards%20addenda/62_1_2013_p_20150707.pdf. [Last accessed on 2 Jul 2024].
60. Senthong P, Wittayasilp S. Working conditions and health risk assessment in hair salons. *Environ Health Insights* 2021;15:11786302211026772. DOI PubMed PMC
61. Melymuk L, Bohlin P, Sáňka O, Pozo K, Klánová J. Current challenges in air sampling of semivolatile organic contaminants: sampling artifacts and their influence on data comparability. *Environ Sci Technol* 2014;48:14077-91. DOI PubMed
62. Grešner P, Świercz R, Wąsowicz W, Gromadzińska J. Faster health deterioration among nail technicians occupationally exposed to low levels of volatile organic compounds. *Int J Occup Med Environ Health* 2017;30:469-83. DOI PubMed
63. Gostner JM, Zeisler J, Alam MT, et al. Cellular reactions to long-term volatile organic compound (VOC) exposures. *Sci Rep* 2016;6:37842. DOI PubMed PMC
64. Moro AM, Brucker N, Charão M, et al. Evaluation of genotoxicity and oxidative damage in painters exposed to low levels of toluene. *Mutat Res* 2012;746:42-8. DOI PubMed
65. Agency for Toxic Substances and Disease Registry. Benzene, toluene, ethylbenzene, and xylenes (BTEX). Available from: https://www.atsdr.cdc.gov/interactionprofiles/ip05.html. [Last accessed on 2 Jul 2024].
66. Occupational Health & Safety. Pieretti LF. Setting a higher standard: the limitations of regulatory limits. 2019. Available from: https://ohsonline.com/articles/2019/10/01/setting-a-higher-standard-the-limitations-of-regulatory-limits.aspx. [Last accessed on 2 Jul 2024].
67. Deveau M, Chen CP, Johanson G, et al. The Global landscape of occupational exposure limits - implementation of harmonization principles to guide limit selection. *J Occup Environ Hyg* 2015;12 Suppl 1:S127-44. DOI PubMed PMC
68. Silva E, Rajapakse N, Kortenkamp A. Something from "nothing" - eight weak estrogenic chemicals combined at concentrations below NOECs produce significant mixture effects. *Environ Sci Technol* 2002;36:1751-6. DOI PubMed
69. Zota AR, Shamasunder B. The environmental injustice of beauty: framing chemical exposures from beauty products as a health disparities concern. *Am J Obstet Gynecol* 2017;217:418.e1-6. DOI PubMed PMC
70. Lothrop N, Sandoval F, Cortez I, et al. Studying full-shift inhalation exposures to volatile organic compounds (vocs) among latino workers in very small-sized beauty salons and auto repair shops. *Front Public Health* 2023;11:1300677. DOI PubMed PMC
71. Ricklund N, Bryngelsson IL, Hagberg J. Occupational exposure to volatile organic compounds (VOCs), including aldehydes for swedish hairdressers. *Ann Work Expo Health* 2023;67:366-78. DOI PubMed PMC
72. ASHRAE. ASHRAE 62.1-2019: Ventilation for acceptable indoor air quality (ANSI approved). 2019. Available from: https://store.accuristech.com/ashrae/standards/ashrae-62-1-2019?product_id=2088533. [Last accessed on 2 Jul 2024].
73. EWG. Big market for black cosmetics, but less-hazardous choices limited. 2016. Available from: https://www.ewg.org/research/big-market-black-cosmetics-less-hazardous-choices-limited. [Last accessed on 2 Jul 2024].