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Biomonitoring of volatile organic compounds (VOCs) among hairdressers in salons primarily serving women of color: A pilot study

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DECLARATION OF COMPETING INTERESTS

The authors declare that they have no competing interests.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

All study protocols were reviewed and approved by the University of Maryland’s Institutional Review Board.

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Abstract

Hairdressers are exposed to volatile organic compounds (VOCs), many of which have been linked to acute and chronic health effects. Those hairdressers serving an ethnic clientele may potentially experience disproportionate exposures from frequent use of products containing VOCs or different VOC concentrations which are marketed to the specific needs of their clientele. However, no biomonitoring studies have investigated occupational exposures in this population. In the present pilot study, we sought to characterize concentrations and exposure determinants for 28 VOC biomarkers in post-shift urine samples among 23 hairdressers primarily serving an ethnic clientele. VOC biomarker concentrations among hairdressers of color were compared to concentrations among a comparison group of 17 office workers and a representative sample of women participating in the U.S. National Health and Nutrition Examination Survey. VOC biomarkers were detected in all hairdressers with higher concentrations observed among hairdressers serving a predominantly Black versus Latino clientele and among hairdressers overall versus office workers or women in the U.S. general population. Median biomarker concentrations for acrolein, 1,3-butadiene, and xylene in hairdressers were more than twice as high as those observed among office workers. Median concentrations for 1-bromopropane, acrolein and 1,3-butadiene were more than four times higher among all hairdressers compared to those reported among women in the U.S. general population. Select salon services (e.g., sister locs, flat ironing, permanent hair coloring, permanent waves or texturizing, Brazilian blowout or keratin treatment, etc.) were also associated with higher VOC biomarker concentrations among hairdressers. This pilot study represents the first biomonitoring analysis to characterize VOC exposures among women hairdressers of color and to provide evidence that this occupational population may experience elevated VOC exposures compared to women in the U.S. general population. Results from our study represent an important first step in elucidating occupational VOC exposures in this understudied occupational group. Larger studies among a racially and ethnically diverse cohort of hairdressers are warranted to confirm our findings and inform future exposure interventions in this understudied occupational population.

Keywords

personal care products; hairdressers; hair salon; volatile organic compounds (VOCs); Black; Latino

INTRODUCTION

There are over 800,000 hairdressers in the U.S., the majority of whom are women.[1] Hairdressers use a wide range of professional salon products resulting in both acute and chronic exposures to a myriad of chemicals present in or emitted from these products. Except for a 2018 California bill requiring professional cosmetics to be labeled,[2] most ingredients in personal care products (i.e., hair and skin care products) are not subject to premarket approval by the U.S. Food and Drug Administration (FDA). They are also not federally mandated to be listed on professional products.[3] The absence of ingredient information for professional salon products makes it difficult to assess the totality of occupational exposures among hairdressers. Still, data shows that some of the chemicals of concern present in or emitted from salon products include volatile organic compounds (VOCs).[4–9] Exposure to VOCs among hairdressers may occur via several routes, including inhalation and dermal absorption.[10–12] Acute VOC exposures may give rise to headaches, dizziness, and eye and respiratory irritation. Chronic exposures in non-occupational populations are reported to increase the risk of birth defects, respiratory illnesses, neurocognitive problems, and cancer.[13–17]

Studies on VOC exposures among hairdressers are sparse and have mainly focused on airborne concentrations of a few VOCs in salons. Although these studies were primarily designed to determine conformity of air quality in hair salons to regulatory standards, their findings signal potentially concerning implications for hairdressers.[4–6,8] For example, one study by Chang et al. determined that airborne formaldehyde levels exceeded the recommended exposure limit (REL) of 0.016 ppm set by the National Institute of Occupational Safety and Health (NIOSH) in a sample of five hair salons in Taipei.[8] Similarly, a U.S. study reported that formaldehyde emissions from a hair treatment known as a Brazilian blowout or keratin smoothing were determined to exceed the NIOSH and American Conference of Governmental Industrial Hygienists' (ACGIH) ceiling limits.[4] Chang et al. also reported that indoor air salon concentrations of other VOCs such as isopropanol, butyl acetate, and ethyl acetate were elevated compared to residential buildings.[8] Taken together, these studies indicate the need to further examine the overall body burden of VOC exposures among hairdressers and to identify modifiable exposure factors to mitigate potentially harmful exposures in this occupational population.

Biomonitoring serves as an effective exposure assessment tool to measure the overall body burden of chemicals from multiple routes. To our knowledge, only one study to date has used biomonitoring to assess VOC exposures among hairdressers. In this study, investigators reported higher urinary concentrations of the VOC parent compounds benzene, toluene, ethylbenzene and xylene (BTEX) among Iranian salon workers compared to controls, but did not conduct a thorough assessment of workplace exposure determinants.[18] Given continual exposures to potentially harmful VOCs among hairdressers, there is a critical need to thoroughly assess these exposures and to identify modifiable exposure sources. In the present pilot study, we used biomonitoring to characterize exposure to 28 VOC biomarkers and assessed occupational exposure determinants in a subsample of U.S. female hairdressers. We focused our subsample exclusively on women of color due to emerging evidence that use of hair care products marketed to this demographic, may give rise to high

chemical exposures among this occupational subgroup.[3,19–28] In addition, we assessed the extent to which being a hairdresser influences VOC exposure by comparing biomarker concentrations in our subsample to those in a comparison group of female office workers as well as a representative sample of women from the U.S. general population.

METHODS

Participant recruitment

Between December 2018 and May 2019 we recruited 23 licensed female hairdressers from six salons in Maryland and the Washington D.C. metropolitan area. Three salons primarily served Blacks/African Americans (i.e., women of Black/African descent) and three salons primarily served Latino clientele. Salons primarily serving a Black/African American clientele provided routine hair relaxing, hair texturizing, and other services catered towards this clientele base, and will thus be referred to herein as “Black” salons. Similarly, salons primarily serving a Latino clientele provided the “Dominican Blowout”, a service that requires hair washing, setting hair in rollers, blow-drying, and, at the client’s request, flat ironing of hair. These salons will be referred to herein as “Dominican” salons. Hair salons were recruited through their salon owners who were identified and recruited with the assistance of community partners, including the Centro de Apoyo Familiar/Center for Assisting Families (CAF) and the Health Advocates In-reach and Research (HAIR) network of the University of Maryland’s School of Public Health. To be eligible to participate in the study, hair salon owners had to be: >18 years of age, have >4 licensed hairdressers employed in their salon at the time of study recruitment, allow access to their salon for three days, and be willing to facilitate the recruitment of hairdressers in their salon. Once recruited, all hair salon owners were further educated about our study protocols and data collection procedures through a series of in-person visits by study staff.

Salon owners granted study staff permission for on-site hairdresser recruitment. Eligibility criteria for hairdressers included women ≥18 years of age who were licensed to work in a salon, reported working in a salon for at least one year prior to study enrollment, and were willing to complete two interviewer-administered questionnaires and provide a urine biospecimen. We recruited a total of 11 hairdressers from Black salons and 12 hairdressers from Dominican salons. All recruited hairdressers were also women of color (Black/African American or Latinas originally from Central America or the Caribbean).

To serve as a comparison group, we recruited a convenience sample of 17 female office workers from the University of Maryland, College Park. Eligibility requirements for this comparison group included women who were ≥18 years, and were willing to complete two interviewer-administered questionnaires and provide a urine biospecimen. Office workers were recruited via email and word of mouth. Participation in the study was voluntary for all study participants and all study protocols were reviewed and approved by the University of Maryland’s Institutional Review Board (IRB). Written informed consent was obtained from salon owners, hairdressers, and office workers prior to study enrollment.

Data and biospecimen collection

Trained bilingual study staff administered two questionnaires to all study participants in their preferred language, English or Spanish. An initial baseline questionnaire elicited information on participant demographics, health-related information (e.g., respiratory and reproductive health), personal and workplace behaviors (e.g., use of personal protective equipment (PPE), and cleaning products at home and work). Workplace behaviors also included information on typical services conducted and products used in the salon by the participant in a usual workweek. On the day of biospecimen collection, participants also completed a second questionnaire at the end of their work shift (i.e., post-shift questionnaire), eliciting information about the services they provided and products they used that day. Except for salon-specific questions, office workers were asked the same questions as hairdressers. All 40 study participants provided post-shift spot urine samples, with participants allowed to void during their work shift. For hairdressers, the timing of the study salon visit (i.e., day of the week) was largely dependent on each hairdresser's availability. The study visit was scheduled either on a "busy" or "non-busy" day as self-designated by the salon owners. Among all collected urine samples, 7 were collected on "busy" days and 16 were collected on "non-busy" days. We limited sampling to the collection of one urine sample per participant due to limited resources and to reduce participant burden.

As reported previously,[29] we also assessed indoor air quality (IAQ) parameters (i.e., CO_2, temperature, and relative humidity) and indoor air contaminants (i.e., particulate matter or PM and select parent VOC compounds) using area samples in each of the six participating salons. Analyses examining IAQ parameters and PM measurements have been published elsewhere[29] with a summary of select results presented in Supplementary Table S1. Selection of the VOC air contaminants in indoor area samples was based on detection feasibility using a standard NIOSH method.[30] Among the 14 parent VOCs measured in air samples, four parent VOC compounds (i.e., benzene, toluene, ethylbenzene and xylene) overlapped with measured urinary VOC biomarkers (air monitoring analyses are currently underway and will be presented elsewhere). Lastly, a description of hair salon services provided by hairdressers participating in the pilot study is available in Supplementary Table S2.

Laboratory analysis

Urine samples were collected in polypropylene, metal-free urine collection cups and aliquoted into 2mL cryovials. All samples were transferred to the lab in an ice chest with ice packs and stored at −80 °C within an hour of collection. Samples remained at −80 °C until shipment on dry ice to the Centers for Disease Control and Prevention (CDC) in Atlanta, GA, for laboratory analysis of VOC biomarkers using a validated laboratory method.[31] Twenty-eight VOC urinary biomarkers were measured, representing exposures to 21 parent VOCs as presented in Table 1. The 28 VOC biomarkers included: N-Acetyl-S-(2-carbamoylethyl)-L-cysteine (2CAEMA), N-Acetyl-S-(N-methylcarbamoyl)-L-cysteine (MCAMA), 2-Aminothiazoline-4-carboxylic acid (2ATCA), N-acetyl-S-(benzyl)-L-cysteine (BZMA), N-Acetyl-S-(n-propyl)-L-cysteine (1-PMA), N-Acetyl-S-(2-carboxyethyl)-L-cysteine (2COEMA), N-Acetyl-S-(1-cyano-2-hydroxyethyl)-L-cysteine (1CYHEMA), N-Acetyl-S-(2-cyanoethyl)-L-cysteine (2CYEMA), N-Acetyl-S-(3,4-dihydroxybutyl)-L-

cysteine (34BMA), N-Acetyl-S-(2-carbamoyl-2-hydroxyethyl)-L-cysteine (2CAHEMA), N-Acetyl-S-(2-hydroxyethyl)-L-cysteine (2HEMA), 5-Hydroxy-N-methylpyrrolidone (5HMP), 5-Hydroxymethyl-2-furoic acid (HMFA), 5-Hydroxymethyl-2-furoylglycine (HMGA), N-Acetyl-S-(2-hydroxypropyl)-L-cysteine (2HPMA), N-Acetyl-S-(3-hydroxypropyl)-L-cysteine (3HPMA), N-Acetyl-S-(3-hydroxypropyl-1-methyl)-L-cysteine (3HMPMA), N-Acetyl-S-(4-hydroxy-2-methyl-2-buten-1-yl)-L-cysteine (4HMBEMA), mandelic acid (MADA), 2-Methylhippuric acid (2MHA), 3-methylhippuric acid (3MHA) + 4-Methylhippuric acid (4MHA), N-Acetyl-S-(4-hydroxy-2-buten-1-yl)-L-cysteine (4HBEMA), muconic Acid (MUCA), N-2-Furoylglycine (N2FG), phenylglyoxylic acid (PHGA), N-Acetyl-S-(1-phenyl-2-hydroxyethyl)-L-cysteine + N-Acetyl-S-(2-phenyl-2-hydroxyethyl)-L-cysteine (1PHHEMA+2PHHEMA), N-Acetyl-S-(phenyl)-L-cysteine (PHMA), and 2-Thioxothiazolidine-4-carboxylic acid (TTCA). Selection of urinary VOC biomarkers was based upon a validated laboratory method,[31] with the goal of comparing VOC biomarker concentrations in our study population to those observed in a representative sample of women from the U.S. general population participating in the National Health and Nutrition Examination Survey (NHANES). Our study samples were analyzed in the same laboratory and with the same analytical method[31] used to measure VOCs in NHANES.

Briefly, urinary VOC biomarker concentrations were quantified using isotope dilution ultra-high performance liquid chromatography (Waters Inc., Milford, MA) coupled with electrospray ionization tandem mass spectrometry (Sciex API 5500 Triple Quad, Applied Biosystems, Foster City, CA) (UPLCESI-MS/MS).[31,32] Urine specimens were assayed with a 1:10 dilution of 50μL urine, 25μL mixed internal standard, and 425μL of a 15mM buffer. Unknown concentrations were quantified using the peak area ratio of a known standard to the stable isotope-labeled internal standard. Limits of detection (LODs) ranged from 0.3 ng/mL to 64.4 ng/mL. Quality control (QC) samples included two spiked urine pools (one low and one high) prepared and characterized using a minimum of 20 analytical runs.[33] Blanks, calibrators, and QC pools were analyzed at the beginning and end of each analytical batch. For quality control, blanks were considered acceptable if their concentration was less < LOD. Calibration curves were fitted for $R^2 \geq 0.98$ using a minimum of five calibrators. QC samples were evaluated to determine whether they were in control according to modified Westgard rules.[33] Analytes with blanks, calibration curves, or QCs that failed any of these requirements were repeated until they met all QC criteria.

To account for urinary dilution, we corrected VOC biomarker concentrations in each sample using specific gravity according to the following formula: $C_{sg} = C \times [(1.019 - 1)/(SG - 1)]$, where C_{sg} is the specific-gravity corrected VOC concentration (ng/ml), C is the observed VOC biomarker concentration (ng/mL), 1.019 is the mean specific gravity for our study population, and is the specific gravity for an individual's urine sample.[34,35] The purpose of applying this formula was to determine whether an individual's sample was dilute or concentrated relative to a given reference value. The benefit of using an internal mean (or median) value for specific gravity is that we are using our own study population as a reference value and are thus able to account for different subpopulation characteristics that may affect urine dilution. Moreover, because we used the same reference value for all participant samples, we were able to evaluate VOC biomarker concentrations across all individuals in our study population. Specific gravity was measured for each individual urine

sample using a handheld refractometer (ATAGO™3741, Tokyo, Japan). After correcting for specific gravity, the percent change in geometric mean concentrations in urinary biomarker concentrations ranged from 10.5% to 11.1%.

Statistical analyses

We calculated descriptive statistics to summarize study population characteristics and to examine differences in demographic and workplace practices between hairdressers from Black and Dominican salons and between hairdressers and office workers. We used Chi-square or Fisher's exact tests to examine differences in frequencies of categorical variables (e.g., race, education level, income). We used the Wilcoxon Mann-Whitney test to examine differences in continuous variables (e.g., age, number of years working in a salon, number of hours worked per day). To further characterize workplace practices among our hairdresser population, we used the Wilcoxon Mann-Whitney test to detect differences in hair salon services provided and products used between hairdressers from Black and Dominican salons.

To characterize urinary VOC biomarker concentrations (ng/mL), we calculated summary statistics for each biomarker, including LOD, detection frequencies (DF), and concentration geometric means, percentiles (p25, p50, p75) and ranges. VOC biomarker concentrations were evaluated as specific gravity-corrected concentrations, and VOC biomarkers < LOD were assigned a value of LOD / $\sqrt{2}$.[36] We stratified summary statistics by salon clientele (i.e., Black and Dominican salons), as well as by occupation (i.e., hairdressers overall vs. office workers). We used the Wilcoxon Mann-Whitney test to detect statistically significant differences in VOC biomarker concentrations between hairdressers from Black and Dominican salons. We also compared summary statistics (i.e., LOD, detection frequency-DF, geometric mean, minimum, median and maximum) for VOC biomarker concentrations between hairdressers and a representative sample of U.S. women using publicly available data from the most recent two-year NHANES cycle (2015–2016). Among NHANES, we selected women of a similar age, race, and ethnicity as our study participants. Since specific gravity is not measured in NHANES, we used uncorrected VOC biomarker concentrations for these comparisons.

While some VOCs have short biological half-lives (i.e., ≤ 8 hours), many have half-lives upwards of 24 hours (Table 1). To capture potential variation of exposure temporality among all hairdressers, we sought to examine VOC biomarker concentrations according to when certain salon services (e.g., extensions with glue, braids, roller set, hair dye) were provided or particular salon products were used (e.g., leave-in conditioner, chemical straightener). Specifically, we compared specific gravity-corrected VOC biomarker concentrations (p_{25}, p_{50}, p_{75}) by whether or not (i.e., Yes/No) participants reported providing each service or using each product on a typical workday, and on the day of urine specimen collection. For these analyses, we used the Wilcoxon Mann-Whitney tests to examine differences in VOC biomarker concentrations. We focused these analyses on VOC biomarker biomarkers with DFs ≥ 60% (5 of 28 VOC biomarker biomarkers were excluded from these analyses). A statistical significance criterion was set at $p<0.05$ for all analyses. All analyses were

conducted using Stata 15.0 software (Stata Corp, College Station, TX), and all supplemental figures were generated using GraphPad Prism 8 Software (San Diego, CA).

RESULTS

Study population characteristics and salon indoor air quality

Nearly all hairdressers (96%) self-identified as either Non-Hispanic Black or Hispanic/Latina, over three quarters (78%) had at least a high school education or trade school training, a little over half (53%) reported an annual income ≤$30,000, and 83% were non-smokers (Table 2). Among office workers, most self-identified as Non-Hispanic Black or Hispanic/Latina (82%), had a college education (71%), reported an annual income of ≥ $30,001 (82%), and were non-smokers (94%). Compared to office workers, hairdressers were older with a mean age of 40 years compared to 34 years respectively (p=0.05). The number of hours worked each week was similar between hairdressers and office workers (44.3 and 40.4 hours worked per week, respectively). In addition, hairdressers reported working an average of 15.1 years in a salon and served an average of 26 clients in a typical workweek.

In comparing hairdressers, those working in Black salons predominantly self-identified as Non-Hispanic Black (91%), while those working in Dominican salons predominantly self-identified as Hispanic/Latina (83%) (Table 2). There was no significant difference in education level; however, all hairdressers working in Black salons had at least a high school education compared to 67% of hairdressers working in Dominican salons. No significant differences in income were observed between hairdressers in Black and Dominican salons. All hairdressers working in Dominican salons were non-smokers, while 36% of hairdressers working in Black salons were smokers (p=0.04). On average, hairdressers working in Dominican salons reported seeing significantly more clients per week than those working in Black salons (33 clients vs. 19 clients, respectively; p = 0.001). There was no significant difference in mean age, number of years worked in hair salons or number of hours worked per week between hairdressers working at Black compared to Dominican salons. Compared to hairdressers working in Dominican salons, a greater percentage of hairdressers working in Black salons provided extensions with adhesives (82% vs 25%, p=0.01), sister locs or locs (dreadlocks) (67% vs 17%, p=0.04), and Afro hairstyle (55% vs 8% p= 0.03) (Table 3). Except for greater hair spray use among hairdressers working in Black salons, the use of other types of products was similar between hairdressers working in Black and Dominican salons.

IAQ parameters for each of the six hair salons have been reported in a previous publication[29] and are reported in Supplementary Table S1. Briefly, CO_2 concentrations (a proxy metric for ventilation) ranged from 687 to 1127ppm, relative humidity ranged from 33.9 to 49.7%, and temperature ranged from 22.5 to 25.4°C in the six hair salons from where participating hairdressers were recruited. CO_2 levels and humidity were generally higher in Black salons.

VOC biomarker concentrations

By salon type—VOC biomarkers were widely detected in hairdressers working in both Black and Dominican salons. While the types of products reported being used did not generally differ between hairdressers in Black and Dominican salons, it is still possible that differences in exposures based on salon type may arise from differences in the chemical content of products being used (e.g., chemical content could differ by brand of product used). In fact, median concentrations for 26 of the 28 VOC biomarkers were higher among hairdressers working in Black salons compared to those working in Dominican salons, with median biomarker concentrations up to 5 times higher among hairdressers working in Black salons (Table 4; Supplemental Figure S1). Median concentrations for 6 biomarkers (2CAEMA, 2COEMA, 2CYEMA, HMFA, HMFG, 3MHA+4MHA) were ≥ 3 times higher among hairdressers working in Black salons compared to those working in Dominican salons. For example, 2CAEMA (acrylamide biomarker) was detected among all hairdressers however, median concentrations were about 4.5 times higher among hairdressers working in Black salons (169 ng/mL) compared to hairdressers working in Dominican salons (37.5 ng/mL). Notably, 2CYEMA (acrylonitrile biomarker) was more widely detected in hairdressers working in Black salons compared to those working in Dominican salons (DF%=91 vs 67%, respectively). Median urinary 2CYEMA concentrations among hairdressers working in Black salons were 5.3 times higher (5.5 ng/mL) than those working in Dominican (1.0 ng/mL) salons. Lastly, median concentrations were <LOD for 1CYHEMA across both groups, and the median concentration for the acrylamide biomarker, 2CAHEMA, was <LOD only for hairdressers working in Dominican salons.

By job title: hairdressers vs office workers

Most VOC biomarkers quantified were higher among hairdressers than office workers (Table 5; Supplemental Figure S2). Apart from MCAMA (biomarker for N,N-Dimethylformamide), median concentrations for all VOC biomarkers were up to 2 times higher in hairdressers versus office workers. Similar detection frequencies were observed for most VOC biomarkers for hairdressers and office workers. For 10 VOC biomarkers (2COEMA, 3HPMA, 34BMA, 4HBEMA, 2HEMA, 2HPMA, 3HMPMA, 4HMBEMA, 3MHA+4MHA, PHGA), significantly higher ($p<0.05$) median levels were noted among hairdressers compared to office workers. Median concentrations for MCAMA, BZMA, and 1CYHEMA were comparable among the two workgroups.

Hairdressers vs. women in the U.S. general population

Median VOC biomarker concentrations were up to 5 times higher among hairdressers compared to a representative sample of U.S. women participating in NHANES 2015–2016 (Table 6). Compared to women in NHANES, hairdressers in our pilot study generally had higher detection frequencies of several VOC biomarkers. Notably, except for PHMA (a benzene biomarker), biomarker LODs were the same in our pilot study and in the NHANES comparison sample. Thus, in general, differences in VOC biomarker detection frequencies are not likely due to differences in method LODs. Of note, the median level of the 1,3-Butadiene biomarker 4HBEMA was more than 5 times higher in hairdressers (17.1ng/mL) compared to U.S. women (3.4ng/mL). Similarly, the biomarkers of acrolein (3HPMA) and

1-Bromopropane (1-PMA) had median concentrations that were more than 4 times higher in hairdressers compared to U.S. women. The median cyanide biomarker, 2ATCA, was similarly higher in hairdressers (390 ng/mL) compared to U.S. women (148 ng/mL).

Comparison with products used, services provided, & workplace behaviors on a typical work-day

Overall, VOC biomarker concentrations were consistently higher when select services were provided than when services were not provided (Table 7). For example, 2HPMA (biomarker for propylene oxide) was significantly higher among hairdressers who reported providing extensions with or without adhesives, twists, and locs. Median concentrations of 2CYEMA (biomarker for acrylonitrile))were also higher among hairdressers who reported providing extensions with or without adhesives, locs, and Afros. Notably, only 1-PMA (biomarker for 1-bromopropane) was higher among those who reported using chemical straighteners or relaxers ($p=0.04$). VOC biomarkers were also generally higher among hairdressers who did not wear a protective mask during a typical work-day. Specifically, higher median levels of MUCA, 5HMP, 1PHHEMA + 2PHHEMA, 4HBEMA, MADA, 34BMA and 2CAEMA were observed among hairdressers who did not wear a mask ($p<0.04$).

Comparison with products used, services provided, and workplace behaviors on the day of urine biospecimen collection

Hairdressers who reported using a semi-permanent formulation of hair coloring had higher median concentrations for several VOC biomarkers representing exposure to four VOC parent compounds, including 5-hydroxymethylfurfural (HMFG, HMFA), toluene/benzyl alcohol (BZMA), and xylene (3MHA+ 4MHA, 2MHA) ($p\leq0.04$) (Table 8). Additionally, hairdressers who reported applying extensions without glue had higher concentrations of four VOC biomarkers, HMFG, 2HPMA, 2CYEMA, and 2MHA ($p\leq0.04$). Hairdressers who reported conducting permanent hair dyeing, roller-setting and hair washing had significantly lower median concentrations for multiple VOC biomarkers (Table 8). Lastly, hairdressers who reported using gloves during chemical-intensive treatments like the Brazilian blowouts and keratin treatments had higher median concentrations for N,N-dimethylformamide and toluene/benzyl alcohol biomarkers, MCAMA ($p=0.04$) and BZMA ($p=0.02$), respectively.

DISCUSSION

We conducted the first characterization of VOC urinary biomarkers among a population of hairdressers who predominantly service an ethnic clientele (i.e., Black and Latino). Our biomonitoring analyses revealed that VOC urinary biomarker concentrations were generally higher among hairdressers compared to similarly aged women in a representative sample of the U.S. general population, higher among hairdressers than office workers, and higher among hairdressers working in Black versus Dominican salons. We showed that exposures to select VOCs are also more prevalent among hairdressers working in Black salons compared to Dominican salons, suggesting that differences in products used or services provided may impact exposures (i.e., biomarkers for acrylonitrile, acrylamide, vinyl chloride, ethylene oxide, and benzene were less widely detected among hairdressers working

in Dominican salons). To our knowledge, no other studies to date have conducted VOC biomonitoring among women hairdressers of color or among hairdressers in the U.S.

In our pilot study, we found that hairdressers who reported typically providing “natural hairstyles” were found to have higher levels of some VOC biomarkers than those hairdressers who reported not providing these same services. For example, those hairdressers typically providing sister locs or locs had higher levels of all reported VOC biomarkers (i.e., TTCA, PGA, 2HPMA, CYEMA) compared to those hairdressers who had not provided these same services. Many personal care product consumer labels do not fully disclose all chemical ingredients in the products, nor account for VOCs or other chemicals that may be formed in indoor air during the use of these products.[19] For example, a recent study found that heating synthetic hair releases VOCs into indoor air.[37] “Natural hairstyles” are perceived to be less harmful or harmless and are often used as an alternative to other chemical-intensive processes such as chemical straightening or relaxing. However, these “natural hairstyles” still entail the use of hair products such as hair oils, moisture treatments, setting lotion, styling gel and hair reconstructor.[38] Thus, it is imperative that further exposure studies characterizing VOCs (and other chemicals of concern), determine exposure pathways for hairdressers and female clientele also seeking “natural” services as these services or styles could still result in exposures of concern.

Interestingly, hairdressers reporting the use of gloves when providing chemical-intensive treatments had higher urinary concentrations of several VOC biomarkers, suggesting that inhalation may be a more important exposure route compared to the dermal route for select VOCs.[39] It is also plausible that this finding is indicative that hairdressers who wear gloves may be more likely to perform salon services and use hair products with harmful active ingredients that potentially pose a greater workplace hazard. We also found that participants who reported frequent use of face masks had lower levels of several VOC biomarkers; however, we did not collect details on the types of protective masks used. Thus, these results may be due to cofounding by other occupational characteristics rather than reflective of the fact that the masks worn were not designed to filter VOCs. PPE focused interventions intended to decrease VOC exposures may require an improved understanding of exposure pathways which may vary based on the types of salon services provided. It is also important to note that product replacement (i.e., use of products free of chemicals of concern) may not always be feasible as not all ingredients are always displayed on product labels and safer alternatives may not always be available, particularly for select demographic groups. For example, a report by the Environmental Working Group indicates that, based on a hazard ranking system that takes into account potential health effects of personal care product ingredients, fewer than 25% of the products marketed to Black women scored low in potentially hazardous ingredients, compared to about 40% of the items marketed to the general public.[38] While the percentage of products scored as “high hazard” was similar for both market segments, the prevalent disparity in products scored as “low hazard” suggests that there is a narrower range of choices for safer-scoring products specifically marketed to women of color.[38]

While smoking could impact exposures to VOCs, unfortunately, we were underpowered to examine the role of smoking status on VOC biomarker concentrations in our study

population. In the present study, 17% of hairdressers (n=4) versus 6% of office workers (n=1) self-identified as smokers. We were also unable to expand upon this analysis by examining the impact of secondhand smoke exposures due to limitations in available data. It is possible that variation in secondhand smoke exposures may have influenced differences observed in select VOC biomarkers between hairdressers in Black salons and Dominican salons. For example, median concentrations for the acrylonitrile biomarker, 2CYEMA, were 5.3 times higher among hairdressers working in Black salons compared to those working in Dominican salons. The biomarker 2CYEMA is a commonly regarded biomarker for acrylonitrile exposures due to tobacco smoke.[40] While the noted increased levels of 2CYEMA may have been due, in part, to differences in secondhand smoke exposure, we could not assess this further. However, this parent compound is also present in many hair products and cosmetics (Table 1); thus, differences in product usage could have also played a role in the observed differences. Collection of information on secondhand smoke exposure and other common sources of VOC exposures will be critical in future studies to ascertain primary VOC exposure sources among hairdressers.

Many VOC biomarkers measured in our study reflect exposures to parent VOCs which are known or suspected endocrine disruptors, carcinogens, respiratory irritants, reproductive toxicants, and neurotoxicants.[3,13–17] Still, the long-term health effects of exposures to individual chemicals and mixtures among hairdressers remain unknown. For many hairdressers of reproductive age, this also translates to being exposed to potentially toxic chemical mixtures during critical windows of susceptibility, including the pre-conception period and pregnancy. In fact, several participants reported previously working in a salon while pregnant, highlighting the importance of an improved understanding of workplace chemical exposures in salon settings. Currently there is an inadequate capacity to enforce occupational health and safety in salon settings at the federal level in the U.S. Instead, occupational health and safety regulations in salon settings are often promulgated by state cosmetology and barbering boards, which can vary by state and seldomly address chemical exposures in salon settings. A key indoor parameter that could help mitigate chemical exposures in salons includes proper ventilation; however, minimum salon ventilation requirements are not clearly delineated for salon owners. For example, sanitation requirements in the state of Maryland where this pilot study was conducted, indicate that licensed salon owners need to ensure that their salon is well ventilated and that select tools like hot combs and flat irons shall be used in well ventilated areas.[41,42] However, interpretation of “well ventilated” is left up to salon owners and further communication with salon owners in our study revealed that they are not aware of resources available to ensure that their salons meet the necessary ventilation requirements based on their unique salon layout and space. The number of salon establishments in every state also places challenges to enforce any laws and regulations dealing with salon worker health and safety. Identifying determinants of chemical exposure in salon settings could inform these regulations and guidelines as well as development of resources to improve worker health and safety in salon settings.

Our study has several limitations, including our small sample size. Limited resources prevented us from characterizing VOC exposures in a larger and more racially/ethnically diverse sample of hairdressers, including hairdressers serving a non-ethnic or mixed

clientele. In addition, limited resources also restricted our ability to collect more than one urine sample per participant. Therefore, it was not possible to assess VOC exposure variability, temporal trends and the extent to which occupational exposures may impact urinary VOC biomarker concentrations. VOC biomarker concentrations may vary within and between individuals due to episodic exposures and variations in bioavailability. Additional sample collections representing a greater distribution of work shift exposures may improve VOC exposure characterizations based solely on spot urine samples.

Furthermore, because VOCs generally have relatively short biological half-lives (< 1 – 24 hours), urine spot samples may not fully represent exposures from products and services assessed in our study or bystander sources, which we were unable to assess. Additionally, it is possible that post-shift samples did not include relevant windows of exposure for certain processes given the extremely short half-lives of some VOC biomarkers, such as 2ATCA and 2HPMA, whose half-lives are < 1 hour.[35,36] Therefore, styling processes conducted early in the day may not be reflected in samples collected post-shift for these VOC biomarkers. Future studies should aim to collect multiple urine samples to better characterize occupational VOC exposures in this study population.

An additional limitation of our study includes our inability to assess other potential influences of indoor air VOC exposures, which may affect detected VOC biomarker concentrations among our study participants. For example, services provided by other hairdressers in the salon could affect indoor air levels of VOCs and subsequent exposures experienced by hairdressers. In addition, possible VOC exposures due to outdoor air may contribute to confounding effects of occupational VOC exposures experienced by hairdressers. Future analyses of VOC biomonitoring studies among hairdressers should consider the collection of salon-wide occupational practices as well as the inclusion of outdoor air sampling around and near participating salons. Still, we previously reported significant differences in respirable particulate matter concentrations between Black and Dominican salons from which we recruited study participants.[29] This suggests that indoor exposures may be at least, in part, due to select services provided and products used in salons.

Despite noted limitations, our study has several strengths. This is the first study to characterize exposure to a large suite of VOCs using biomonitoring methods among minority hairdressers primarily serving a female clientele of color. To our knowledge, no other peer-reviewed studies have quantified urinary VOC biomarkers among minority hairdressers. Another strength of our study was having two comparison groups, including office workers and a representative sample of women from the U.S. general population. This allowed for a comprehensive evaluation of chemical exposures in our target occupational subgroup, as well as an understanding of how their exposures may compare to those of populations considered to be lesser exposed. An additional strength is that our study is the first to examine VOC exposures among hairdressers in the context of products, services, and workplace behaviors, including the use of PPE. This allowed us to identify potential modifiable exposure factors which could help inform future interventions to mitigate exposures in this occupational population, including changes in workplace behaviors (i.e., use of PPE, increased ventilation, etc.), use of alternative chemical treatments as well as an

increase in workplace education, such as safer work practices in the hair service industry. Future studies in larger and more racially/ethnically diverse population of hairdressers are needed to identify modifiable exposure factors and potential risk disparities based on race ethnicity of hairdressers and/or clientele served. Such studies could also help inform regulations of potentially harmful chemical ingredients as well as the reformulation of current products. These studies may also help inform the determination and designation of current and future relative exposure limits for occupational indoor air exposures to VOCs in salon settings.

CONCLUSIONS

In summary, our findings suggest that hairdressers of color, primarily serving women of color, generally had higher VOC biomarker levels than office workers and women in the U.S. general population. These findings add to the evidence that hairdressers are continually exposed to a myriad of chemicals linked to adverse health effects. In addition, studies among hairdressers serving women of color are critically needed, as the specific repertoire of products used and services provided by this group may pose unique health risks.[19,22] Our study represents an important first step toward understanding exposures among this understudied population, and is critical to the larger goal of reducing exposures should they be disproportionate. In the future, it will also be important to examine exposures associated with “natural hairstyles” among hairdressers serving women of color. The perception that “natural hairstyles” are safer than chemical-intensive services has implications both for hairdressers and clientele who may seek out these services as strategies to minimize personal exposures. Lastly, our findings underscore the need for larger studies to better inform exposure mitigation strategies in this understudied and underrepresented occupational group.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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HIGHLIGHTS

- This is the first VOC biomonitoring study among female hairdressers of color
- Higher VOC biomarker concentrations in hairdressers serving Black versus Latino clientele
- Select salon services were associated with higher VOC biomarker concentrations
- Hairdressers had higher concentrations for several VOC biomarkers than office workers
- Hairdressers had higher concentrations for several VOC biomarkers than U.S. women

Table 1.

Characteristics and sources of parent VOCs and respective urinary biomarker measured.[a]

Parent Compound	Biological Half-Life	Biomarker Chemical Name	Biomarker Abbreviation	Sources of exposure in hair salons, thru products used and services provided[a]	Other common sources of exposure, outside of hair salons
1,3-Butadiene	10 hours[32]	N-Acetyl-S-(3,4-dihydroxy butyl)-L-cysteine, N-Acetyl-S-(4-hydroxy-2-butenyl)-L-cysteine	34BMA, 4HBEMA	hair fixers, shampoo, nail polish, sunscreen, moisturizer, body wash/cleanser, eyeliner, bronzer[33–37]	tobacco smoke, vehicle exhaust, waste incineration or wood fires, tires, various synthetic rubber products, paints, aerosol sprays, nitrile gloves[35,38–41]
1-Bromopropane	up to 6.2 hours. Bromide ion takes longer to expel[42]	N-Acetyl-S-(n-propyl)-L-cysteine	1-PMA	scissor lubricant[35]	aerosol spray, adhesives and spot removers, glass cleaner, wood surface cleaner, textile cleaning solvent, metal-degreasing solvent, paints[35,38,40,43]
5-Hydroxymethylfurfural	up to 6.2 hours at 2,700 ppm. Bromide ion takes longer to expel. Varies with concentration of gas[44]	5-Hydroxymethyl-2-furoic acid, 5-Hydroxymethyl-2-furoylglycine	HMFA, HMGA	N/A—used in cosmetics in general, but no details provided on actual products[45,46]	cigarette smoke, beverages and foods[40]
Acrolein	10 hours[47]	N-Acetyl-S-(3-hydroxypro pyl)-L-cysteine, N-Acetyl-S-(2-carboxyeth yl)-L-cysteine	3HPMA, 2COEMA	hair fixative, artificial nail builder[48]	tobacco smoke, automotive exhaust, oil or coal fired plants, cooking oil[38,39,41]
Acrylamide	up to 25 hours (2CAHEMA), up to 17 hours (2CAEMA)[49]	N-Acetyl-S-(2-carbamoyle thyl)-L-cysteine, N-Acetyl-S-(2-carbamoyl-2-hydroxyethyl)-L-cysteine	2CAEMA, 2CAHEMA	shampoo, nail polish, hair styling gel, conditioner, styling mousse/foam, hair treatment/serum, detangler, anti-wrinkle cream, day cream, night cream, eye cream, mattifier, make-up removal cloths, serum, eye treatment, mascara, makeup primer, bath oil/salts, body wash, moisturizer[35,37,50]	tobacco smoke, carbohydrate-rich foods such as potatoes cooked at high temperatures, contaminated well water, working in the production or use of acrylamide and acrylamide containing products, soil conditioning agents, spot treatment, liquid fabric conditioner[35,38,40,41]
Acrylonitrile	7–8 hours[51]	N-Acetyl-S-(2hydroxyethyl)-L-cysteine, N-Acetyl-S-(1-cyano-2-hy droxyethyl)-L-cysteine, N-Acetyl-S-(2-cyanoethyl)-L-cysteine	2HEMA, 1CYHEMA, 2CYEMA	hair wigs and extensions, body wash, perfume, nitrile gloves[35,52,53]	tobacco smoke, industrial sources or hazardous waste sites, synthetic and acrylic fibers of textiles, resins, plastics, and rubber for a variety of consumer goods[38,40,41]
Benzene	up to 1.2 hours[54,55]	Muconic Acid, N-Acetyl-S-(phenyl)-L-cysteine	MUCA, PHMA	hair styling cream[50] hair styling cream[50]	tobacco smoke, automobile service stations, exhaust from motor vehicles, and industrial emissions, dishwasher liquid detergent, laundry soap[35,38]
Carbon disulfide	6.5 hours[56]	2-Thioxothiazolidine-4-carboxylic acid	TTCA	N/A	tobacco smoke, manufacturing processing (e.g. rayon and rubber products), but likely not found in the final product[38,39,57]
Crotonaldehyde	< 1 day[58]	N-Acetyl-S-(3-hydroxypro pyl-1-methyl)-L-cysteine	3HMPMA	perfumes and fragrances[59]	tobacco smoke, gas cookers, gasoline and diesel engine exhausts, and smoke from wood burning, naturally occur in some

Parent Compound	Biological Half-Life	Biomarker Chemical Name	Biomarker Abbreviation	Sources of exposure in hair salons, thru products used and services provided[a]	Other common sources of exposure, outside of hair salons
					foods, uncontrolled hazardous waste sites[38]
Cyanide	20 minutes - 1 hour[60]	2-Aminothiazoline-4-carboxylic acid	2ATCA	N/A	Tobacco smoke, found in cyanide containing foods, used in plastic production of dyes, but insignificant amount released, environmental pollution from mines, metallurgical plants, and exhaust gas from vehicles[38,61]
Ethylbenzene / Styrene	8 hours[62]	Phenylglyoxylic acid	PHGA	sunscreens, moisturizer with SPF, nail polish, body firming lotion, facial sun care, body wash/cleanser, facial moisturizer/ treatment, eye liner, mascara, foundation, BB cream, facial powder, makeup with SPF, lip balm, facial cleanser, serums & essences, baby soap, toners/astringents, eyelash glue, tanning sprays, eye shadow, hair wigs and extensions, shampoo, hair styling aide, baby shampoo[37,63,64]	tobacco smoke, vehicle exhaust, building materials, manufacturing, foods and beverages, foods packaged in polystyrene containers, liquid hand soap[35,38–41]
Furfural	2 – 2.5 hours[65]	N-2-Furoylglycine	N2FG	NA	flavoring agents for foods, Lysol All Purpose Cleaner[35,66]
Isoprene	10.2 hours[67]	N-Acetyl-S-(4-hydroxy-2-methyl-2-buten-1-yl)-L-cysteine	4HMBEMA	hair bonding glue, eye shadow, eyeliner, eyelash glue, face and body paint[37,68]	rubber products, vehicle tires[40]
N,N-Dimethylformamide	23 hours[69]	N-Acetyl-S-(N-methylcarbamoyl)-L-cysteine	MCAMA	hair dye[70]	tobacco smoke, building materials, glues[38,39,41]
N-Methyl-2-pyrrolidone	4 hours[71]	5-Hydroxy-N-methylpyrrolidone	5HMP	antifungal nail treatment, mascara, nail polish remover,[37]	paint thinners, glue, cleaning detergents[72,73]
Propylene oxide	40 minutes[74]	N-Acetyl-S-(2-hydroxypro pyl)-L-cysteine	2HPMA	conditioner, shampoo, texturizing cream, hair dye,[35,37]	tobacco smoke, plastics industry, lubricants, oil demulsifiers, antimicrobial pesticides, building and construction materials[39–41,74]
Styrene	2.2 – 9 hours[75,76]	Mandelic acid, N-Acetyl-S-(1-phenyl-2-hydroxyethyl)-L-cysteine + N-Acetyl-S-(2-phenyl-2-hydroxyethyl)-L-cysteine	MADA, 1PHHEMA + 2PHHEMA	hair wigs and extensions, shampoo, conditioner, hair spray, hair serum, shaving cream, perfume and fragrances, deodorant spray, body lotion, cologne, shower gel, body mist, face masks, body cream, hand cream[50,63,64]	tobacco smoke, vehicle exhaust, building materials, manufacturing, foods and beverages, foods packaged in polystyrene containers[38–41]
Toluene / Benzyl alcohol	52 mins for phase I 12.95 hours for phase II[77]	N-Acetyl-S-(benzyl)-L-cysteine	BZMA	hair dyes, hair sprays, hair wigs and extensions, shampoo, conditioner, hair treatment/serum, hair bleach, hair styling aide, detangler, styling gel/lotion, styling mousse/foam, beach & sport sunscreen, lipstick, moisturizer, moisturizer with SPF, facial moisturizer/treatment, foundation, body wash/cleanser, fragrance for women and men, body firming lotion, lip gloss, eye	tobacco smoke, fossil fuels, dyes, industrial solvent, paints, paint thinners, liquid hand soap,[35,38,39,41]

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Parent Compound	Biological Half-Life	Biomarker Chemical Name	Biomarker Abbreviation	Sources of exposure in hair salons, thru products used and services provided[a]	Other common sources of exposure, outside of hair salons
				shadow, facial-cleanser, serums & essences, baby sunscreen, mask, bronzer/highlighter, facial sun care, exfoliant/scrub, lip balm with SPF, hand cream, mascara, makeup remover, antiperspirant/deodorant, shaving cream, lip balm, eye cream, facial powder, BB cream, bubble bath, lip liner, toners/ astringents, concealer, brow liner, eye liner, makeup with SPF, toothpaste, baby lotion, sunless tanning, body oil, blush, shaving cream (men's), after shave, after sun product, bath oil/salts/soak, CC cream, foot moisturizer, mouthwash, body spray, oil controller, vapor rubs, anti-aging cream, baby bubble bath & wipes, bar soap, skin fading/lightener, lip plumper, tanning spray.[37,63,64]	
Vinyl chloride	4.1 – 4.6 hours in rats[78]	N-Acetyl-S-(2-hydroxyethyl)-L-cysteine	2HEMA	hair spray[79]	tobacco smoke, breathing contaminated air from plastics industries, hazardous waste sites and landfills, drinking water from contaminated wells[38,41]
Xylene	1.5 hours[80]	2-Methylhippuric acid, 3-Methylhippuric acid + 4-Methylhippuric acid	2MHA, 3MHA + 4MHA	conditioner, pressing oil, bleaching cream[35,37,81]	tobacco smoke, gasoline, paint, varnish, shellac, rust preventatives, air emissions from paint industries and automobile garages[38,39,41]

[a] May include personal care and hair styling products.

Table 2.

Study population characteristics of hairdressers and office workers (N=40).

	All Hairdressers (N=23)	Office Workers (N=17)		Hairdressers from Black Salons (N=11)	Hairdressers from Dominican Salons (N=12)	
	n (%)	n (%)	p-value[a]	n (%)	n (%)	p-value[a]
Race						
Hispanic/Latina	11 (47.8)	7 (41.2)	0.52	1 (9.1)	10 (83.3)	**0.0001**
Non-Hispanic Black	11 (47.8)	7 (41.2)		10 (90.9)	1 (8.3)	
Other[b]	1 (4.4)	3 (17.6)		0 (0)	1 (8.3)	
Highest Education Obtained						
< High School	4 (17.4)	0 (0)	**<0.0001**	0 (0)	4(33.3)	0.21
High School or GED	6 (26.1)	1 (5.9)		4 (36.4)	2 (16.7)	
Trade School	8 (34.8)	1 (5.9)		4 (36.4)	4 (33.3)	
College	5 (21.7)	12 (70.6)		3 (27.3)	2 (16.7)	
Other	0 (0)	3 (17.7)		0 (0)	0 (0)	
Income[d]						
≤ $30,000	10 (52.6)	3 (17.7)	0.10	5 (45.5)	5 (62.5)	0.59
$30,001–$50,000	4 (21.1)	3 (17.7)		2 (18.2)	2 (25.0)	
$50,001–$75,000	2 (10.5)	4 (23.5)		1 (9.0)	1 (12.5)	
> $75,000	3 (15.8)	7 (41.2)		3 (27.3)	0 (0)	
Smoking Status						
No	19 (82.6)	16 (94.1)	0.37	7 (63.6)	12 (100.0)	**0.04**
Yes	4 (17.4)	1 (5.9)		4 (36.4)	0 (0)	
	Mean (SD)	**Mean (SD)**	**p-value[c]**	**Mean (SD)**	**Mean (SD)**	**p-value[c]**
Age (years)	40.2 (10.6)	33.6 (7.9)	0.05	37.3 (10.2)	42.8 (10.6)	0.22
Number of years working in hair salons	15.1 (9.5)	n/a		14.9 (9.4)	15.3 (10.1)	0.83
Number of hours worked during the week	44.3 (18.7)	40.4 (10.4)	0.73	46.2(23.7)	42.6 (13.4)	0.69
Number of clients per week	26.2 (12.1)	n/a		19.2 (8.8)	32.7 (11.4)	**0.001**

[a] p-values based on Chi-square or Fischer's exact test, where appropriate

[b] Other race categories include: White, Asian, American Indian or Alaska Native, and Other.

[c] p-values based on Wilcoxon-Mann Whitney Test.

[d] Four hairdressers did not report income.

Significant findings are listed in **boldface** ($p < 0.05$).

Abbreviation: SD, Standard Deviation.

Table 3.

Hair salon services provided and products used by hairdressers (n=23).

	Hairdressers from Black Salons (N=11)	Hairdressers from Dominican Salons (N=12)	
Services provided	**n (%)**	**n (%)**	**p-value[a]**
Permanent waves or texturizing	5 (46)	9 (75)	0.22
Chemical straightening or relaxing	10 (90)	9 (75)	0.59
Bleaching or highlights	9 (82)	11 (92)	0.59
Semi-permanent hair coloring	10 (90)	8 (67)	0.32
Permanent hair coloring	10 (90)	11 (92)	1.00
Hair extensions (no adhesives or chemicals)	9 (82)	5 (42)	0.09
Hair extensions (with adhesive or other chemicals)	**9 (82)**	**3 (25)**	**0.01**
Hair drying with a blow dryer	11 (100)	12 (100)	-
Flat ironing or curling with a curling iron	11 (100)	11 (92)	1.00
Putting hair in rollers	10 (90)	9 (75)	0.59
Brazilian blowout or keratin treatment	7 (64)	7 (58)	1.00
Braids on afro hair	4 (36)	4 (33)	0.10
Twists	8 (73)	5 (42)	0.21
Sister locs or locs (dreadlocks)	**7 (67)**	**2 (17)**	**0.04**
Afros (natural hairstyle)	**6 (55)**	**1 (8)**	**0.03**
Haircut	9 (82)	9 (75)	1.00
Hair washing	11 (100)	12 (100)	-
Deep conditioner	11 (100)	11 (92)	1.00
Products Used			
Shampoo	11 (100)	12 (100)	-
Leave-in conditioner or detangler	11 (100)	10 (83)	0.48
Conditioner	11 (100)	12 (100)	-
Hair spray	**11 (100)**	**7 (58)**	**0.04**
Hair oil	11 (100)	11 (92)	1.00
Hair gel or pomade	11 (100)	10 (83)	0.48
Hair mousse	11 (100)	11 (92)	1.00
Bleach or highlights	9 (82)	10 (83)	1.00
Hair dye	11 (100)	11 (92)	1.00
Chemical straightener or relaxer	10 (90)	9 (75)	0.59
Products for permanent waves and texturizers	6 (55)	7 (58)	1.00
Keratin treatment/Brazilian blowout	7 (67)	3 (25)	0.10

[a] p-values based on Chi-square or Fischer's exact test, where appropriate

Significant findings are listed in **boldface** ($p < 0.05$).

Table 4.

Summary statistics for specific gravity-corrected urinary VOC biomarker concentrations (ng/ml) among hairdressers by salon type.[a,b]

		Hairdressers from Black Salons (N=11)					Hairdressers from Dominican Salons (N=12)				
Biomarker	**LOD**	**DF%**	**GM**	**Min**	**p50 (p25-p75)**	**Max**	**DF%**	**GM**	**Min**	**p50 (p25-p75)**	**Max**
2CAEMA	2.2	100	133	21.1	**169 (61.2–253)**	463	100	40.7	15.9	**37.5 (21.0–67.7)**	200
2CAHEMA	9.4	82	20.4	<LOD	23.7 (10.0–34.5)	109	42	<LOD	<LOD	<LOD	36.8
MCAMA	6.26	100	168	22.3	159 (109–282)	1,240	100	88.1	47.1	90.9 (56.9–120)	186
2ATCA	15	91	493	<LOD	**802 (390–1210)**	1,980	100	244	51.0	**289 (120–465)**	1150
BZMA	0.5	100	21.8	1.69	**26.3 12.9–46.8)**	148	100	9.86	1.56	**10.8 (3.17–22.2)**	160
1-PMA	1.2	100	19.7	1.32	18.0 (2.26–115)	307	83	11.8	<LOD	12.2 (3.49–24.3)	730
2COEMA	6.96	100	262	13.7	**309 (238–426)**	701	100	113	43.9	**89.9 (56.2–206)**	554
3HPMA	13	100	940	40.9	1070 (642–2360)	3,490	100	505	78.5	666 (235–1150)	1,890
1CYHEMA	2.6	18	<LOD	<LOD	<LOD	157	0	<LOD	<LOD	<LOD	<LOD
2CYEMA	0.5	91	8.22	<LOD	**5.46 (2.51–35.9)**	504	67	0.977	<LOD	**1.04 (<LOD-1.95)**	4.37
34BMA	5.25	100	651	60.6	**742 (500–1260)**	1,690	100	369	145	**412 (247–602)**	683
4HBEMA	0.6	100	20.1	1.19	22.3 (10.3–44.6)	111	100	9.98	2.76	9.56 (3.80–18.5)	67.6
2HEMA	0.791	91	2.88	<LOD	**2.9 (1.96–5.2)**	9.49	58	1.15	<LOD	**1.28 (<LOD-2.1)**	3.13
HMFA	36.1	100	7160	531	**7,810 (2,890–30,600)**	31,700	100	2,320	434	**2080 (1160–4290)**	16,400
HMFG	16	100	779	74.7	1020 (217–2,350)	2,640	100	344	82.8	338 (156–1610)	1,610
5HMP	0.3	100	95.6	16.3	**123 (63.4–148)**	202	100	44.5	8.11	**48.6 (22.2–103)**	193
2HPMA	5.3	100	70.4	5.59	**94.1 (62.0–118)**	183	100	32.0	9.99	**47.75 (12.45–59.6)**	69.8
3HMPMA	3	100	793	46.2	616 (528–2,060)	6,500	100	534	101	699 (412–925)	1,650
4HMBEMA	1.2	91	13.6	<LOD	13.1 (8.72–22.2)	120	100	7.25	1.48	11.4 (2.36–17.9)	22.7
MADA	12	100	320	24.8	**299 (228–662)**	1,710	100	26.3	26.3	**191 (128–26.0)**	487
1PHHEMA + 2PHHEMA	0.7	82	2.30	<LOD	3.19 (1.51–4.10)	9.44	58	1.24	<LOD	1.57 (<LOD-2.60)	3.93
3MHA + 4MHA	8	100	355	45.7	**385 (206–628)**	1,380	100	84.4	20	**118 (37.9–152)**	242
2MHA	5	100	47.4	11.2	**40.5 (31.9–92.1)**	135	92	13.1	<LOD	**14.9 (7.02–27.6)**	33.2
MUCA	9.81	91	115	<LOD	**113 (74.6–307)**	572	100	41.8	18	**39.2 (25.0–62.1)**	170
PHMA	0.15	64	0.308	<LOD	0.208 (<LOD-0.329)	4.23	42	<LOD	<LOD	<LOD	0.504

			Hairdressers from Black Salons (N=11)				Hairdressers from Dominican Salons (N=12)				
Biomarker	**LOD**	**DF%**	**GM**	**Min**	**p50 (p25-p75)**	**Max**	**DF%**	**GM**	**Min**	**p50 (p25-p75)**	**Max**
N2FG	64.4	100	9,320	1830	8,620 (2,540–21,900)	182,000	100	4,200	1000	3,520 (1,560–9,960)	22,800
PHGA	12	100	458	34.1	**458 (353–556)**	2340	100	238	68.7	**283 (162–381)**	560
TTCA	11.2	91	45.3	<LOD	44.1 (28.7–83.3)	153	83	36.7	<LOD	29.1 (19.6–58.1)	843

[a] GM and percentile values are only reported when > 50% of participant samples had detectable levels.

[b] Wilcoxon-Mann Whitney test was used to compare differences in median VOC biomarker concentrations between hairdressers working in Black versus Dominican Salons.

Significant findings are listed in **boldface** ($p < 0.05$).

Abbreviations: LOD, Limit of detection; DF, Detection Frequency; GM, Geometric Mean; p#: represents percentiles.

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Table 5.

Summary statistics for specific gravity-corrected urinary VOC biomarker concentrations (ng/ml) among hairdressers and office workers.[a,b]

		All Hairdressers (N=23)					Office Workers (N=17)				
Biomarker	**LOD**	**DF%**	**GM**	**Min**	**p50 (p25-p75)**	**Max**	**DF%**	**GM**	**Min**	**p50 (p25-p75)**	**Max**
2CAEMA	2.2	100	80.5	21.3	80.2 (36.5–154)	328	100	64.2	20.5	63.1 (44.9–98.7)	273
2CAHEMA	9.4	61	15.9	<LOD	16.7 (<LOD-27.2)	89.6	41	<LOD	<LOD	<LOD	23.7
MCAMA	6.26	100	135	47.7	112.3 (75.1–238)	880	100	111	43.2	118 (66.5–183)	382
2ATCA	15	96	383	<LOD	378 (220–805)	1500	100	249	82.1	263 (171–306)	609
BZMA	0.5	100	16.2	3.54	15.3 (8.45–22.8)	122	100	11.6	2.15	10.3 (5.94–15.30	281
1-PMA	1.2	91	16.9	<LOD	12.6 (5.76–73.7)	555	94	7.01	<LOD	8.21 (2.81–14.4)	148
2COEMA	6.96	100	189	38.0	**207 (143–312)**	497	100	106	31.2	**126 (77.4–165)**	178
3HPMA	13	100	763	241	**832 (551–1,110)**	2480	100	395	76.4	**394 (302–662)**	2370
1CYHEMA	2.6	9	<LOD	<LOD	<LOD	111	6	<LOD	<LOD	<LOD	6.55
2CYEMA	0.5	78	3.04	<LOD	2.35 (1.33–4.42)	358	65	1.75	<LOD	1.26 (<LOD-1.87)	34.2
34BMA	5.25	100	543	260	**505 (386–814)**	1110	100	350	162	**365 (310–484)**	775
4HBEMA	0.6	100	15.6	4.63	**14.9 (9.75–23.6)**	78.7	94	6.59	<LOD	**7.03 (5.00–8.78)**	39.3
2HEMA	0.791	74	2.00	<LOD	**2.33 (1.48–3.19)**	7.54	59	1.32	<LOD	**1.27 (<LOD-1.85)**	4.57
HMFA	36.1	100	4470	366	4,850 (2,050–11,600)	25200	100	3380	130	3,940 (2,460–6,960)	19,500
HMFG	16	100	570	51.4	668 (284–1470)	2180	94	424	<LOD	552 (241–934)	2,500
5HMP	0.3	100	72.0	21.2	77.6 (38.8–124)	220	100	73.6	28.2	68.7 (47.5–105)	239
2HPMA	5.3	100	52.3	18.0	**53.1 (38.9–77.8)**	130	100	36.0	12.6	**36.9 (22.9–50.5)**	162
3HMPMA	3	100	724	331	**653 (459–1100)**	4610	100	436	202	**430 (301–596)**	974
4HMBEMA	1.2	96	11.0	<LOD	**9.79 (7.23–14.6)**	85.1	100	4.89	2.46	**5.51 (3.25–6.47)**	8.77
MADA	12	100	257	118	218 (193–334)	1,210	100	187	81.0	199 (158–226)	380
1PHHEMA + 2PHHEMA	0.7	70	1.87	<LOD	1.97 (<LOD-2.68)	6.70	71	1.29	<LOD	1.42 (<LOD-1.76)	2.79
3MHA + 4MHA	8	100	188	55.0	**179 (91.3–339)**	979	100	114	34.8	**84.2 (69.7–110)**	13,800
2MHA	5	96	27.2	<LOD	25.1 (20.1–48.3)	151	94	17.1	<LOD	11.5 (10.1–27.0)	94.0
MUCA	9.81	96	75.9	<LOD	71.9 (32.8–155)	750	88	71.9	<LOD	69.5 (29.7–143)	661
PHMA	0.15	52	0.255	.073	0.240 (0.128–0.455)	3.00	12	<LOD	<LOD	<LOD	.378

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		All Hairdressers (N=23)					Office Workers (N=17)				
Biomarker	**LOD**	**DF%**	**GM**	**Min**	**p50 (p25-p75)**	**Max**	**DF%**	**GM**	**Min**	**p50 (p25-p75)**	**Max**
N2FG	64.4	100	6,900	982	7040 (2300–17300)	150,000	100	8440	351	6,260 (4,160–18,900)	88,700
PHGA	12	100	365	200	**324 (280–458)**	1,660	100	267	119	**271 (217–337)**	628
TTCA	11.2	87	45.6	<LOD	41.5 (21.1–66.0)	869	88	35.4	<LOD	28.2 (12.7–53.3)	1,850

[a] GM and percentile values are only reported when > 50% of participant samples had detectable levels.

[b] Wilcoxon-Mann Whitney test was used to compare differences in median VOC biomarker concentrations between all hairdressers and office workers.

Significant findings are listed in **boldface** ($p < 0.05$).

Abbreviations: LOD, Limit of detection; DF, Detection Frequency; GM, Geometric Mean; p#: represents percentiles.

Table 6.

Summary statistics for uncorrected urinary VOC biomarker concentrations (ng/mL) among hairdressers and women in the U.S. general population (NHANES 2015–2016).[a,b]

	All Hairdressers (N=23)						NHANES participants (N= 3,278)					
Biomarker	**LOD**	**DF%**	**GM**	**Min**	**p50 (p25-p75)**	**Max**	**LOD**	**DF%**	**GM**	**Min**	**p50 (p25-p75)**	**Max**
2CAEMA	2.2	100	71.7	15.9	61.2 (25.8–186)	463	2.2	99	45.0	<LOD	43.3 (20.4–92.1)	1,110
2CAHEMA	9.4	61	14.2	<LOD	11.5 (<LOD-25.8)	109	9.4	39	<LOD	<LOD	<LOD	114
MCAMA	6.26	100	120	22.3	109 (59.0–186)	1,240	6.26	99	124	<LOD	127 (56.1–259)	2,060
2ATCA	15	96	342	<LOD	390 (144–926)	1,980	15	99	136	<LOD	148 (66.6–285)	1,590
BZMA	0.5	100	14.4	1.56	17 (5.7–31.2)	160	0.5	99	5.46	<LOD	5.55 (2.55–11.2)	1,330
1-PMA	1.2	91	15.1	<LOD	16.1 (2.26–107)	730	1.2	81	4.04	<LOD	3.56 (1.33–8.63)	707
2COEMA	6.96	100	169	13.7	233 (66.9–313)	701	6.96	99	79.9	<LOD	79.3 (40.3–152)	1460
3HPMA	13	100	680	40.9	944 (366–1700)	3,490	13	99	228	<LOD	203 (98.8–505)	6,970
1CYHEMA	2.6	9	<LOD	<LOD	<LOD	157	2.6	20	<LOD	<LOD	<LOD	304
2CYEMA	0.5	78	2.71	<LOD	2.14 (0.635–5.46)	504	0.5	77	2.94	<LOD	1.27 (0.511–15.1)	1320
34BMA	5.25	100	484	60.6	572 (285–742)	1,690	5.25	100	261	19.7	280 (142–488)	2,400
4HBEMA	0.6	100	13.9	1.19	17.1 (6.45–33.8)	111	0.6	93	4.11	<LOD	3.36 (1.72 8.84)	201
2HEMA	0.791	74	1.79	<LOD	1.96 (<LOD-3.13)	9.49	0.791	46	<LOD	<LOD	<LOD	49.4
HMFA	36.1	100	3980	434	3460 (1210–15700)	31,700	--	--	--	--	--	--
HMFG	16	100	508	894	587 (197–1370)	2,640	--	--	--	--	--	--
5HMP	0.3	100	64.2	8.11	79.6 (42.7–129)	202	--	--	--	--	--	--
2HPMA	5.3	100	46.6	5.59	60.5 (33.7–94.1)	183	5.3	93	29.5	<LOD	26.9 (13.9–56.4)	1,680
3HMPMA	3	100	646	46.2	630 (528–1130)	6,500	3	100	389	21.8	357 (165–773)	15,400
4HMBEMA	1.2	96	9.81	<LOD	13.1 (5.66–19.2)	120	1.2	76	4.25	<LOD	3.30 (1.30–9.10)	357
MADA	12	100	229	24.8	228 (165–336)	1,710	12	98	113	<LOD	122 (59.6–221)	4,330
1PHHEMA + 2PHHEMA	0.7	70	1.67	<LOD	1.86 (<LOD −3.31)	9.44	0.7	46	<LOD	<LOD	<LOD	14.8
3MHA + 4MHA	8	100	168	20.0	193 (96.1–385)	1,380	8	99	182	<LOD	201 (66.3–472)	99,20
2MHA	5	96	24.3	<LOD	29.5 (10.5–40.5)	135	5	91	30.63	<LOD	33.7 (11.5–79.6)	1660
MUCA	9.81	96	67.7	<LOD	62.3 (26.0–160)	572	--	--	--	--	--	--

	All Hairdressers (N=23)						NHANES participants (N= 3,278)					
Biomarker	**LOD**	**DF%**	**GM**	**Min**	**p50 (p25-p75)**	**Max**	**LOD**	**DF%**	**GM**	**Min**	**p50 (p25-p75)**	**Max**
PHMA	0.15	52	0.228	0.106	0.173 (0.106–0.457)	4.23	0.6	43	<LOD	<LOD	<LOD	28
N2FG	64.4	100	6160	1000	6530 (2320–15300)	182000	--	--	--	--	--	--
PHGA	12	100	325	34.1	378 (259–502)	2340	12	99	172	<LOD	175 (89.3–355)	5320
TTCA[c]	11.2	87	40.6	<LOD	39.2 (25.2–59.4)	843	11.2	35	<LOD	<LOD	<LOD	1130

[a]GM and percentile values are only reported when > 50% of participant NHANES samples had detectable levels.

[b]For NHANES analyses, only women ages 21–58 years were included. NHANES data is weighted to account for the complex survey design. Sample sizes reported are reflective of the 2015–2016 NHANES publicly available data, unless otherwise noted.

[c]Data for TTCA was not available for the NHANES 2015–2016 cycle, so data from the 2013–2014 cycle (n=612) was used instead.

Note: -- denotes data not available in NHANES.

Abbreviations: LOD: Limit of detection; DF: Detection Frequency; GM: Geometric Mean; p#: represents percentiles.

Table 7.

Specific gravity-corrected urinary VOC biomarker concentrations (ng/mL) among hairdressers by services provided, products used, and PPE used on a typical workday (N=23).[a]

	Biomarker	Was service provided, product used or PPE used?[b]	n (%)	p50 (p25, p75)	p-value[c]
Type of service provided					
Extension no glue	2HPMA	Yes	14 (61)	63.5 (51.1, 83.7)	0.02
		No	9 (39)	39.1 (24.2, 53.3)	
	2CYEMA	Yes	14 (61)	3.45 (1.67, 4.77)	0.01
		No	9 (39)	1.44 (1.18, 1.55)	
	3MHA + 4MHA	Yes	14 (61)	235(133.517)	0.04
		No	9 (39)	91.3 (69.4, 195)	
	2MHA	Yes	14 (61)	39.0 (23.2, 75.9)	0.04
		No	9 (39)	23.9 (18.1, 25.1)	
Extension with glue	HMFA	Yes	12 (52)	8.620 (4200, 12400)	0.04
		No	11(48)	2.040 (868, 6400)	
	2HPMA	Yes	12 (52)	71.7 (52.1, 93.9)W0	0.02
		No	11 (48)	44.6 (28.6, 53.3)	
	2CYEMA	Yes	12 (52)	3.45 (1.97, 4.66)	0.02
		No	11 (48)	1.52 (0.560, 2.36)	
	2ATCA	Yes	12 (52)	687 (405, 839)	0.01
		No	11 (48)	248 (188, 378)	
	3MHA + 4MHA	Yes	12 (52)	302 (166, 481)	0.01
		No	11(48)	91.3 (69.0, 195)	
Roller set	BZMA	Yes	19(83)	17.6 (10.1, 30.9)	0.04
		No	4 (17)	7.23 (4.78 12.8)	
Braids	HMFA	Yes	12 (52)	11600 (4200.18300)	0.01
		No	11 (48)	2700 (868, 6400)	
	5HMP	Yes	12 (52)	87.2 (66.6, 180)	0.04
		No	11 (48)	43.7 (38.2, 91.5)	
Twists	2HPMA	Yes	13 (57)	68.0 (51.5, 80.6)	0.04
		No	10(43)	41.8 (24.2, 53.3)	
Sister locs or locs	TTCA	Yes	9 (39)	63.5 (57.8.107)	0.01
		No	14 (61)	28.6 (10.1, 41.5)	
	PHGA	Yes	9 (39)	458 (333, 463)	0.03
		No	14 (61)	299 (275, 371)	
	2HPMA	Yes	9 (39)	75.3 (53.1, 80.6)	0.04
		No	14 (61)	46.1 (28.6, 53.5)	
	2CYEMA	Yes	9 (39)	3.58 (3.29 4.77)	0.01

		No	14 (61)	1.53 (1.18, 2.35)	
Afros	PHGA	Yes	7 (30)	458 (333, 498)	0.02
		No	16 (70)	299 (271, 374)	
	34BMA	Yes	7 (30)	814 (455, 868)	0.04
		No	16 (70)	456 (368, 639)	
	2CYEMA	Yes	7 (30)	4.42 (3.33, 39.4)	<0.0001
		No	16 (70)	1.53 (1.25, 2.36)	
	TTCA	Yes	7 (30)	63.5 (57.4, 107)	0.04
		No	16 (70)	34.6 (20.6, 54.2)	
Type of product used					
Used leave in conditioner	5HMP	Yes	21 (91)	79.9 (49.9 124)	0.04
		No	2 (9)	36.7 (36.1, 37.3)	
	3HPMA	Yes	21 (91)	837 (611, 1100)	0.03
		No	2 (9)	289 (241, 337)	
Used chemical straightener or relaxer	1-PMA	Yes	19(83)	17.8 (7.22, 79.2)	0.04
		No	4 (17)	4.30 2.74, 7.95)	
Type of PPE used					
Wear masks	MUCA	Yes	5 (22)	40.2 (32.8, 40.9)	0.03
		No	18(78)	87.7 (59.2, 171)	
	5HMP	Yes	5 (22)	38.2 (37.3, 38.8)	0.01
		No	18(78)	87.2 (53.0, 130)	
	1PHHEMA + 2PHHEMA	Yes	5 (22)	1.23 (1.13, 1.36)	0.03
		No	18(78)	2.27 (1.40, 3.77)	
	4HBEMA	Yes	5 (22)	9.26 (8.71, 10.32)	0.02
		No	18(78)	16.53 (11.8, 26.8)	
	MADA	Yes	5 (22)	171(170,193)	0.01
		No	18(78)	237(199,340)	
	34BMA	Yes	5 (22)	386 (341, 407)	0.01
		No	18(78)	639 (455, 817)	
	2CAEMA	Yes	5 (22)	36.1 (32.5, 44.0)	0.04
		No	18(78)	93.3 (72.7, 174)	

[a]Analyses were only conducted when VOC biomarker concentration DFs ≥ 60%; only significant findings are reported in the table.

[b]Based on initial baseline questionnaire.

[c]Wilcoxon-Mann Whitney test was used to compare differences in median VOC biomarker concentrations. Abbreviations: p#: represents percentiles.

Table 8.

Specific gravity-corrected urinary VOC biomarker concentrations (ng/mL) among hairdressers by services provided, products used, and PPE used on the day of biospecimen collection (N=23).[a]

	VOC biomarker	Was service provided, product used or PPE used?[b]	n (%)	p50 (p25, p75)	p-value[c]
Type of Service Provided					
Semi-permanent hair coloring	HMFG	Yes	4 (17)	1360 (926, 1980)	0.04
		No	19(83)	481 (217, 1200)	
	HMFA	Yes	4 (17)	17000 (9270, 23500)	0.02
		No	19(83)	3790 (1330, 10220)	
	BZMA	Yes	4 (17)	41.8 (18.5, 91.9)	0.04
		No	19(83)	12.6 (7.47, 21.5)	
	3MHA + 4MHA	Yes	4 (17)	432(342,574)	0.01
		No	19(83)	137 (85.8, 270)	
	2MHA	Yes	4 (17)	62.6(45.9,76.6)	0.02
		No	19(83)	24.6 (18.1, 35.0)	
Permanent hair coloring	MADA	Yes	5 (22)	196(124,199)	0.04
		No	18(78)	237 (194, 340)	
	3HMPMA	Yes	5 (22)	424 (369, 452)	<0.0001
		No	18(78)	716(601,1250)	
Extension no glue	HMFG	Yes	4 (17)	687 (405, 839)	0.03
		No	19(83)	248 (188, 378)	
	2HPMA	Yes	4 (17)	78.0(67.1, 105)	0.04
		No	19 (83)	51.11 (34.7, 68.1)	
	2CYEMA	Yes	4 (17)	4.59 (3.39, 181)	0.04
		No	19(83)	1.58 (1.32, 3.33)	
	2MHA	Yes	4 (17)	72.6(38.6,123)	0.02
		No	19(83)	24.6 (18.1, 42.6)	
Hair drying with blow dryer	2HEMA	Yes	8 (35)	1.73 (0.764, 2.27)	0.03
		No	15(65)	3.02 (1.61, 3.80)	
Roller set	MUCA	Yes	6 (26)	32.5 (28.2, 54.6)	0.01
		No	17 (74)	93.5 (59.2, 171)	
	2HP	Yes	6 (26)	33.7 (24.2, 39.1)	0.01
		No	17 (74)	58.9 (51.1, 80.6)	
	2CYEMA	Yes	6 (26)	0.870 (0.439, 1.33)	<0.0001
		No	17 (74)	3.29 1.59, 4.55)	
	2COEMA	Yes	6 (26)	121 (67.8163)	<0.0001
		No	17 (74)	279 (188, 316)	
	3MHA + 4MHA	Yes	6 (26)	80.4 (69.0,137)	0.04
		No	17 (74)	200(133,346)	

	2MHA	Yes	6 (26)	12.0 (4.39, 24.8)	0.02
		No	17 (74)	27.9 (23.9, 49.3)	
Braids	2ATCA	Yes	3 (13)	1300 (826, 1500)	0.01
		No	20 (87)	335 (219, 544)	
Hair washing	N2FG	Yes	14 (61)	3420 (1620, 8310)	<0.0001
		No	9 (39)	18200 (16900, 26600)	
	HMFG	Yes	14 (61)	444 (191, 668)	<0.0001
		No	9 (39)	1470 (908, 1780)	
	HMFA	Yes	14 (61)	2810 (930, 4850)	0.01
		No	9 (39)	11500 (7020, 13200)	
	AMCA	Yes	14(61)	77.0 (65.5, 146)	0.01
		No	9(39)	217 (170, 297)	
	2MHA	Yes	14(61)	22.3 (14.7, 27.9)	0.01
		No	9(39)	42.9(26.9, 75.9)	
Type of PPE used					
Gloves	MCAMA	Yes	14 (64)	106 (44.0, 204)	0.04
		No	8 (36)	54.6 (34.3, 76.9)	
	BZMA	Yes	14 (64)	18.5 (12.6, 30.9)	0.02
		No	8 (36)	7.96 (5.37, 13.9)	

[a] Analyses were only conducted where VOC biomarker concentration ≥ 60%.

[b] Based on post work-shift questionnaire.

[c] Wilcoxon-Mann Whitney test was used to compare differences in median VOC biomarker concentrations Abbreviations: p#: represents percentiles.