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Exposure Characterization and Assessment of Airborne Chemicals and SARS-CoV-2 Transmission in New York City Nail Salons

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EXPOSURE CHARACTERIZATION AND ASSESSMENT

OF AIRBORNE CHEMICALS AND SARS-CoV-2 TRANSMISSION

IN NEW YORK CITY NAIL SALONS

A DISSERTATION

By

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Dissertation Abstract

Title: Exposure Characterization and Assessment of Airborne Chemicals and SARS-Cov-2 Transmission In New York City Nail Salons

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Background: Currently, there are 156,000 people employed as manicurists or pedicurists in the United States. Employment in this sector is expected to grow by 10% over the next decade. Exposure assessments have revealed that salon workers are chronically exposed to a variety of substances that cause respiratory sensitization, developmental problems, contact dermatitis, blood, liver, and kidney issues, as well as nervous system impacts. Most recently, the SARS-Cov-2 pandemic has raised the issue of the vulnerability of nail salon workers to airborne infectious diseases as well. This dissertation aims to characterize and assess the chemical exposures that nail salon workers face and the transmission potential of the highly infectious SARS-Cov-2 in nail salons in New York City.

Methods: The first study in this dissertation is a systematic review of the literature to characterize airborne chemical exposures in nail salons in the United States using the Office for Health Assessment and Translation (OHAT) framework. The systematic review included studies that conducted environmental monitoring and those that explored health effects related to occupational exposure in nail salons. The second aim involved environmental monitoring in 12 nail salons in New York City to measure pollutant concentrations and estimate ventilation rates using carbon dioxide concentrations as a proxy measurement. Aim 3 focused on modeling the transmission potential of SARS-Cov-2 in nail salons in New York City using five realistic scenarios. The nail salons that participated in aims 2 and 3 were chosen using convenience sampling.

Results: In the first study, the evidence in the included studies showed that nail salon workers are exposed to a variety of volatile organic compounds (VOCs) and particulate matter. Generally, the concentrations for most chemicals have declined over the past 30 years. Few studies investigated health outcomes and found that nail salon workers often experience acute symptoms such as headaches and dizziness, coughing, nausea, and irritation of mucosal membranes. Chronic symptoms included nervous system damage. In the second study, we found that most (XX%) New York City nail salons tested were not in compliance with New York State regulations to have exhaust ventilation systems installed. Toluene, methyl methacrylate (MMA), and ethyl acetate were detected in salons but only a quarter of samples of toluene and MMA were above the limit of detection (LOD). In salons that did have general exhaust ventilation, indoor pollutant concentrations were lower. We also found that carbon dioxide (CO_2) concentrations were a significant good predictor of indoor air quality in the nail salons. In study 3, we found the risk of SARS-CoV-2 airborne infection transmission across all salons and all exposure scenarios when not wearing face masks ranged from <0.015% to 99.25%. Wearing face masks reduced airborne infection transmission risk to between <0.01% and 51.96%, with an average airborne infection transmission risk of 7.30% across all salons. Increased outdoor airflow rates in nail salons were generally strongly correlated with decreased average airborne infection transmission risk.

Conclusions: These studies highlight some of the indoor air pollution hazards that nail salon workers face. Exposure to low concentrations of chemicals can cause acute symptoms, but repeated long-term exposures may cause lasting health problems and should be explored further. Additionally, the synergistic or additive effects of low-level exposures is unknown. There is a need

for more epidemiological studies to explore the associations between exposure to nail salon products and specific health outcomes. Reducing exposures to vapors, particulates, and pathogens requires installing or improving ventilation systems, using personal protective equipment (PPE) such as gloves and appropriate masks/respirators and, eliminating products with harmful chemicals. The results of aims 2 and 3 showed that salons with appropriate ventilation rates had lower levels of airborne chemicals and a lower risk of transmissions of SARS-CoV-2 infectious particles. These measures will serve to benefit both workers and patrons of nail salons.

DEDICATION

In the hopes that this work may in some way contribute to a safer and healthier workplace, this dissertation is dedicated to nail salon workers everywhere. To, Dr. Brian Pavilonis, for your unwavering support, patience, and mentorship, I dedicate this dissertation to you.

Table of Contents

List of Tables

List of Figures

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Chapter 1 **Introduction**

1.1 The Nail Salon Industry

The nail salon industry has experienced a dramatic transformation over the past two decades. Today, revenue generated by the industry has surpassed $8 billion.[1] In the United States (U.S.) alone, there are currently 156,000 people employed as manicurists or pedicurists, and employment in this sector is expected to grow by 10% over the next decade.[1] This number is likely underestimated and is thought to be closer to 400,000[2] due to high job misclassification rates, unlicensed nail technicians, and undocumented workers in this employment sector[3]. Approximately 30% of nail salon workers are self-employed or independent contractors and have fewer workplace protections than full-time employees.[3] In the U.S., most of research on nail salons has been based in California, where the industry initially expanded the fastest, with far less research conducted elsewhere. In New York City (NYC), there are approximately 2,000 nail salons;[4] the majority are owned by Korean and Chinese immigrants. The NYC metropolitan area has the highest concentration of nail salon employment in the U.S.[1] According to U.S. Census data, more than 79% of all nail salon workers are foreign-born, 96% are female, 46% do not speak English or lack English proficiency, and most are uninsured or lack access to healthcare.[5] Nail salon workers disparately face routine ergonomic, chemical, physical, safety, and biological hazards in the workplace.[6] In addition to these long-existing issues, the current SARS-CoV-2 pandemic has presented new health and safety challenges for already vulnerable nail salon workers. Unlike other job sectors, there exists no information about injury and illness in the nail salon industry published by the U.S. Bureau of Labor Statistics (BLS) or elsewhere. However, the published literature has grown substantially over the past few decades and indicates there is need to support these vulnerable populations through increased research and advocacy to inform federal and state policies.

1.2 Occupational exposures and health outcomes in nail salon workers

Several studies have revealed the occupational exposures and suspected health effects that nail salon workers have faced over the past two decades. A small but developing body of epidemiological research has shown associations between nail salon workers' tasks and many adverse health outcomes. Exposure assessments have revealed that nail salon workers are chronically exposed to a variety of volatile organic compounds (VOCs), the "Toxic Trio" (toluene, formaldehyde, and dibutyl phthalate), BTEX (benzene, toluene, ethylbenzene, and xylenes), acetates, alcohols, acetone, and acrylates. These chemicals are found in nail polishes, nail polish removers and solvents, artificial nails and nail glues, and acrylic powders and gels (Table 3.1).

Repeated exposures to these chemicals for years have led to reports of neurological[8–10], dermal[8,11–13], respiratory[12–14], and musculoskeletal effects[12,15–17] by nail salon workers. A study of California nail salon workers reported that skin and eye irritation, difficulty breathing, and headaches were experienced by almost half of the surveyed workers, symptoms that are characteristic of solvent exposure.[18] Acetones and acetates (ethyl, butyl, isopropyl) are solvents often used in high volumes that commonly irritate the skin, nose, mouth, throat, and eyes.[19] In a similar survey of Southeast Asian immigrant nail salon workers in California, the most frequently reported symptoms were nose irritation and allergies. Those who worked with acrylic nails were more likely to self-report "poor" or "fair" health.[14] These findings have been similar to those in studies conducted outside of the U.S.[20–23]

Table 1-1 Common nail salon chemicals, sources, and health effects

Chemical	Products	Health effects
Acetone	Nail polish remover	Headaches, dizziness, and irritation*
Acetonitrile	Fingernail glue remover	Irritation, breathing problems, nausea, vomiting, weakness, and exhaustion.
Butyl acetate	Nail polish, nail polish remover	Headaches and irritation
Dibutyl phthalate (DBP)	Nail polish	Nausea and irritation
Ethyl acetate	Nail polish, nail polish remover, fingernail glue	Irritation, high concentrations can cause fainting.
Ethyl methacrylate (EMA)	Artificial nail liquid	Asthma, irritation, difficulty concentrating, teratogenic
Formaldehyde	Nail polish, nail hardener	Difficulty breathing, coughing, asthma-like attacks, wheezing, allergic reactions, irritation, cancer.
Isopropyl acetate	Nail polish, nail polish remover	Sleepiness and irritation.
Methacrylic acid	Nail primer	Skin burns and irritation, difficulty breathing.
Methyl methacrylate (MMA)	Artificial nail products	Asthma, irritation, difficulty concentrating, loss of smell.
Toluene	Nail polish, fingernail glue	Dry or cracked skin, headaches, dizziness, and numbness, irritation, and liver and kidney damage, teratogenic

Note: This table is adapted from *Stay Healthy and Safe While Giving Manicures and Pedicures: A Guide for Nail Salon Workers*.[7]
*: refers to irritation of the skin and mucosal membranes, including eyes, nose, throat, mouth, and stomach

Longer-term health outcomes have been linked to some chemicals, such as the "Toxic Trio." Formaldehyde is used in nail polish as a hardener and has been classified as "carcinogenic to humans" based on animal and human studies.[24] Toluene in nail polish forms a smooth surface over the nail and has been linked to reproductive and nervous system impacts.[25–27] DBP is used to make nail polishes less brittle and is a developmental and reproductive toxin.[28,29] Another group of chemicals associated with long-term health effects is acrylates. Methyl methacrylate (MMA), ethyl methacrylate (EMA), and other acrylates used in artificial nails are associated with permanent paresthesia[9–11], allergic contact dermatitis, and occupational asthma.[30,31] In one retrospective observational study, among 122 individuals who underwent allergen patch testing with MMA, 37 individuals were allergic, of whom 28 were nail technicians.[32] Although the concentrations detected for most of these chemicals are several orders of magnitude below occupational exposure limits, the additive or synergistic effects of these chemical compounds are unknown, and evaluating exposure on a chemical-by-chemical basis may be inappropriate for chemical mixtures. The objective of this study was to characterize concentrations of airborne chemicals in nail salons and document any health outcomes in the peer-reviewed literature.

1.3 New York nail salon regulations

In 2015, the Office of the Governor of New York announced that nail salons throughout New York State (NYS) would have to comply with new ventilation regulations (Section 160.16) to protect employees and clients from exposure to airborne chemicals in salons. [33,34] This decision came after a highly controversial exposé was published in the New York Times newspaper that detailed the poor workplace conditions and labor law violations that nail salon workers face.[35,36] Subsequently, a task force was deployed from the governor of New York State's office to investigate the claims reported in the exposé.[37] The new regulations stipulated that all salons licensed before October 2016 will have five years to meet compliance, while those licensed after October 2016 must meet the ventilation requirements upon establishing the business.[34] The new ventilation requirements incorporate the 2015 International Mechanical Code (2015 IMC), which specifies general exhaust ventilation (GEV) and local exhaust ventilation (LEV) standards for nail salons and hair salons that provide nail services [38]. The GEV requirement is a function of occupant density and area of the salon with a minimum of 20 cfm (cubic feet per minute) of outdoor airflow per person, plus an additional 0.12 cfm per 1000 ft^2. When the occupant density is unknown, a default value of 25 people per 1000 ft^2 is required. The LEV requirements are for a source-capture hood placed within

12 inches of manicure and pedicure task areas and exhausted directly outside at a rate no less than 50 cfm per nail station [38]. No recirculation of salon air is permitted.

1.4 SARS-CoV-2 pandemic: A new threat

In March 2020, New York City became a hot-spot for SARS-CoV-2 infections, and to curb the transmission rate, New York state mandated all non-essential services, which included nail salons, to close.[39] In the months that followed, the information that guided the reopening of businesses was scant and generic but essentially guided by density reduction measures, social distancing, and the use of face coverings since the virus is spread through airborne transmission.[40,41] In July 2020, New York entered Phase III of reopening, which allowed personal care services to resume.[40] The nature of personal care services requires close contact, and there was a general concern about the ability of these service providers and clients to interact without compromising safety. The combination of personal protective equipment (PPE) along with engineering controls such as properly functioning ventilation systems could potentially reduce the transmission rate of the disease as well as the long-standing chemical exposures that workers have faced for decades, but the effectiveness is unknown and further research needs to be done.

1.5 Overall Goals of Dissertation

Though substantial progress has been made in characterizing the airborne hazards in nail salons in the U.S. and abroad, gaps in the literature still require novel explorations in nail salon research or additions to existing investigations. Previous studies have identified most of the chemicals in nail salons that workers are exposed to and the related health effects of many of them, though not all the associations have been proven to be causal. A thorough literature review is often a great tool for professionals who need a point of reference. As such, there is a need for appraisal of the peer-reviewed literature on the specifics of airborne chemical exposures in nail salons and the associated health outcomes of those chemicals. Identifying the chemicals is just the first step and should be followed by exploring mitigation measures to reduce harmful exposures. The use of mechanical ventilation systems to improve the indoor air quality in nail salons should be further explored in New York City, especially considering the looming deadline of the nail salons mandate to install ventilation systems. Additionally, the SARS-CoV-2 pandemic has presented new challenges for nail salon workers and owners tasked with protecting their employees and clients alike. The effectiveness of ventilation systems and face coverings to reduce viral transmission should be explored in more detail.

This dissertation's overall goal was to address these gaps in the literature and contribute to the current information that will reduce the harmful chemical exposures that nail salon workers face and explore long-term solutions moving forward. This dissertation focused on specifically characterizing the chemical, airborne exposures to nail salon workers and their associations with documented acute and chronic health outcomes. A systematic review tool was used to accomplish this goal. This dissertation's second goal was to examine the temporal variability of key air pollutants generated in nail salons in New York City and determine if the existing ventilation systems meet established standards. This study's third goal was inspired by the lack of information about infection transmission of SARS-CoV-2 in indoor spaces and presented a timely opportunity to explore this hazard from an occupational exposure perspective in nail salons.

1.6 Specific Aims and Hypotheses

The dissertation aims complement each other to characterize airborne chemical exposures in nail salons in the United States, explore a new biological airborne hazard, and discuss the use of ventilation as a mitigative measure to reduce these exposures. The following are the specific aims for this dissertation and the associated hypotheses:

Specific Aim 1: Systematically review the literature to characterize the occupational airborne exposures that nail salons workers face in the United States and investigate the documented health outcomes.

H_0= Workers who are exposed to airborne chemicals in nail salons will not exhibit symptoms characteristic of exposure to the individual chemicals.

Specific Aim 2: Measure indoor air pollutants and estimate ventilation rates in New York City nail salons.

H_0= Ventilation rate is not correlated with indoor air pollution concentrations.

Specific Aim 3: Estimate the transmission potential of SARS-CoV-2 in nail salons in New York City using ventilation rates from specific aim 2 and five realistic exposure scenarios.

H_0=Transmission potential is not affected when ventilation rates increase and when masks are worn.

1.7 References

1. U.S. Department of Labor, Bureau of Labor Statistics. Occupational Outlook Handbook, Manicurists and Pedicurists. Published September 4, 2019. Accessed January 5, 2020. https://www.bls.gov/ooh/personal-care-and-service/manicurists-and-pedicurists.htm?view_full#tab-6
2. Nails Magazine. Nail technician demographics. Published online 2014.
3. Sharma P, Waheed, S, Stepick L, et al. *Nail Files. A Study of Nail Salon Workers and Industry in the United States*. UCLA Labor Center and California Healthy Nail Salon Collaborative; 2018. https://www.labor.ucla.edu/wp-content/uploads/2018/11/NAILFILES_FINAL.pdf
4. Federman MN, Harrington DE, Krynski KJ. The Impact of State Licensing Regulations on Low-Skilled Immigrants: The Case of Vietnamese Manicurists. *American Economic Review*. 2006;96(2):237-241. doi:10.1257/000282806777211630
5. U.S. Census Bureau. 2012-2016 ACS 5-year Estimates. The United States Census Bureau. Published June 12, 2019. Accessed March 30, 2021. https://www.census.gov/programs-surveys/acs/technical-documentation/table-and-geography-changes/2016/5-year.html

6. OSHA. Health Hazards in Nail Salons - Chemical Hazards. Accessed July 10, 2019. https://www.osha.gov/SLTC/nailsalons/chemicalhazards.html
7. US Department of Labor, Occupational Safety and Health Administration (OSHA). *Stay Healthy and Safe While Giving Manicures and Pedicures: A Guide for Nail Salon Workers.* American Psychological Association (APA); 2012.
8. Freeman S, Lee M-S, Gudmundsen K. Adverse contact reactions to sculptured acrylic nails: 4 case reports and a literature review. *Contact Dermatitis*. 1995;33(6):381-385. doi:10.1111/j.1600-0536.1995.tb02071.x
9. Guin JD, Baas K, Nelson-Adesokan P. Contact sensitization to cyanoacrylate adhesive as a cause of severe onychodystrophy. *International Journal of Dermatology*. 1998;37(1):31-36. doi:10.1046/j.1365-4362.1998.00252.x
10. Baran RL, Schibli H. Permanent Paresthesia to Sculptured Nails: A Distressing Problem. *Dermatologic Clinics*. 1990;8(1):139-142. doi:10.1016/S0733-8635(18)30538-2
11. Belsito DV. Contact dermatitis to ethyl-cyanoacrylate-containing glue. *Contact Dermatitis*. 1987;17(4):234-236. doi:10.1111/j.1600-0536.1987.tb02719.x
12. Park S-A, Gwak S, Choi S. Assessment of Occupational Symptoms and Chemical Exposures for Nail Salon Technicians in Daegu City, Korea. *J Prev Med Public Health*. 2014;47(3):169-176. doi:10.3961/jpmph.2014.47.3.169
13. Kopelovich L, Perez AL, Jacobs N, Mendelsohn E, Keenan JJ. Screening-level human health risk assessment of toluene and dibutyl phthalate in nail lacquers. *Food and Chemical Toxicology*. 2015;81:46-53. doi:10.1016/j.fct.2015.04.011
14. White H, Khan K, Lau C, Leung H, Montgomery D, Rohlman DS. Identifying Health and Safety Concerns in Southeast Asian Immigrant Nail Salon Workers. *Archives of Environmental & Occupational Health*. 2015;70(4):196-203. doi:10.1080/19338244.2013.853644
15. Roelofs C, Azaroff LS, Holcroft C, Nguyen H, Doan T. Results from a Community-based Occupational Health Survey of Vietnamese-American Nail Salon Workers. *J Immigrant Minority Health*. 2008;10(4):353-361. doi:10.1007/s10903-007-9084-4
16. Lax MB, Grant WD, Manetti FA, Klein R. Recognizing occupational disease-taking an effective occupational history. *Am Fam Physician*. 1998;58(4):935-944. Accessed June 17, 2019. http://europepmc.org/abstract/med/9767728
17. Harris-Roberts J, Bowen J, Sumner J, et al. Work-related symptoms in nail salon technicians. *Occupational Medicine*. 2011;61(5):335-340. doi:10.1093/occmed/kqr096
18. Quach T, Nguyen K-D, Doan-Billings P-A, Okahara L, Fan C, Reynolds P. A preliminary survey of Vietnamese nail salon workers in Alameda County, California. *J Community Health*. 2008;33(5):336-343. doi:10.1007/s10900-008-9107-7
19. OSHA (Occupational Safety and Health Administration). *Stay Healthy and Safe While Giving Manicures and Pedicures: A Guide for Nail Salon Workers*.; 2012. https://www.osha.gov/Publications/3542nail-salon-workers-guide.pdf.
20. Sanaat S, Holness DL, Arrandale VH. Health and Safety in Nail Salons: A Cross-Sectional Survey. *Ann Work Expo Health*. Published online July 30, 2020. doi:10.1093/annweh/wxaa078
21. Tran HM, Bui HTM, Thoumsang S, et al. Occupational symptoms due to exposure to volatile organic compounds among female Vietnamese nail salon workers in Danang city. *J Occup Health*. 2020;62(1):e12160. doi:10.1002/1348-9585.12160
22. Park S-A, Gwak S, Choi S. Assessment of occupational symptoms and chemical exposures for nail salon technicians in Daegu City, Korea. *J Prev Med Public Health*. 2014;47(3):169-176. doi:10.3961/jpmph.2014.47.3.169
23. Moradi M, Hopke P, Hadei M, et al. Exposure to BTEX in beauty salons: biomonitoring, urinary excretion, clinical symptoms, and health risk assessments. *ENVIRONMENTAL MONITORING AND ASSESSMENT*. 2019;191(5). doi:10.1007/s10661-019-7455-7
24. Cogliano V, Grosse Y, Baan R, Straif K, Secretan B, Ghissassi FE. Advice on formaldehyde and glycol ethers. *The Lancet Oncology*. 2004;5(9):528. doi:10.1016/S1470-2045(04)01562-1

25. Donald J M, Hooper K, Hopenhayn-Rich C. Reproductive and developmental toxicity of toluene: a review. *Environmental Health Perspectives*. 1991;94:237-244. doi:10.1289/ehp.94-1567945
26. Mørck H, Winkel P, Gyntelberg F. Health effects of toluene exposure. *Danish medical bulletin*. 1988;35(2):196-200. http://europepmc.org/abstract/MED/3359818
27. Filley CM, Halliday W, Kleinschmidt-Demasters BK. The Effects of Toluene on the Central Nervous System. *Journal of Neuropathology & Experimental Neurology*. 2004;63(1):1-12. doi:10.1093/jnen/63.1.1
28. Howdeshell KL, Furr J, Lambright CR, Rider CV, Wilson VS, Gray LE Jr. Cumulative Effects of Dibutyl Phthalate and Diethylhexyl Phthalate on Male Rat Reproductive Tract Development: Altered Fetal Steroid Hormones and Genes. *Toxicological Sciences*. 2007;99(1):190-202. doi:10.1093/toxsci/kfm069
29. Ema M. Antiandrogenic effects of dibutyl phthalate and its metabolite, monobutyl phthalate, in rats. *Congenital Anomalies*. 2002;42(4):297-308. doi:https://doi.org/10.1111/j.1741-4520.2002.tb00896.x
30. Sauni R, Kauppi P, Alanko K, Henriks-Eckerman M-L, Tuppurainen M, Hannu T. Occupational asthma caused by sculptured nails containing methacrylates. *American Journal of Industrial Medicine*. 2008;51(12):968-974. doi:10.1002/ajim.20633
31. Lozewicz S, Davison AG, Hopkirk A, et al. Occupational asthma due to methyl methacrylate and cyanoacrylates. *Thorax*. 1985;40(11):836-839. doi:10.1136/thx.40.11.836
32. Ramos L, Cabral R, Gonçalo M. Allergic contact dermatitis caused by acrylates and methacrylates--a 7-year study. *Contact Derm*. 2014;71(2):102-107. doi:10.1111/cod.12266
33. International Code Council, Inc. *Section 160.16 of Part 160 of Title 19 of the New York Codes, Rules and Regulations*.; 2016. https://www.dos.ny.gov/licensing/appearance/ventingreg.html
34. Office of the Govenor, New York State. Governor Cuomo Announces New Ventilation Standards For Nail Salons. Governor Andrew M. Cuomo. Published July 22, 2016. Accessed June 18, 2019. https://www.governor.ny.gov/news/governor-cuomo-announces-new-ventilation-standards-nail-salons
35. Nir SM. The Price of Nice Nails. *The New York Times*. https://www.nytimes.com/2015/05/10/nyregion/at-nail-salons-in-nyc-manicurists-are-underpaid-and-unprotected.html. Published May 7, 2015. Accessed March 31, 2021.
36. Nir SM. Perfect Nails, Poisoned Workers. *The New York Times*. https://www.nytimes.com/2015/05/11/nyregion/nail-salon-workers-in-nyc-face-hazardous-chemicals.html. Published May 8, 2015. Accessed March 31, 2021.
37. Bernstein R. What the 'Times' Got Wrong About Nail Salons. The New York Review of Books. Published July 25, 2015. Accessed March 31, 2021. https://www.nybooks.com/daily/2015/07/25/nail-salons-new-york-times-got-wrong/
38. NYS Department of State. *Ventilation Requirements For Nail Specialty Services Guidance Document For Contractors And Design Professionals*.; 2016. https://www.dos.ny.gov/licensing/appearance/NailSalon%20Technical%20document.%20final.pdf
39. Office of the Govenor, New York State. No. 202: Declaring a Disaster Emergency in the State of New York. Governor Andrew M. Cuomo. Published March 7, 2020. Accessed May 17, 2020. https://www.governor.ny.gov/news/no-202-declaring-disaster-emergency-state-new-york
40. New York State Governor's Office. Governor Cuomo Announces New York City Enters Phase III of Reopening Without Indoor Dining and Subject to State Guidance Today. Governor Andrew M. Cuomo. Published July 6, 2020. Accessed August 22, 2020. https://www.governor.ny.gov/news/governor-cuomo-announces-new-york-city-enters-phase-iii-reopening-without-indoor-dining-and
41. Office of the Govenor, New York State. Executive Order 202.14, VOLUME A-1a (Title 10). Part 66, SubPart 66-3, Section 66-3.2 - Face-Coverings. Published July 9, 2020. Accessed August 21, 2020. https://regs.health.ny.gov/volume-1a-title-10/content/section-66-32-face-coverings

Chapter 2 : Characterization of airborne occupational exposures in nail salons in the United States: A systematic review using the OHAT framework.

2.1 Introduction

Employment in the nail salon sector (manicurists and pedicurists) accounted for more than 156,000 jobs in the United States in 2019 and is expected to grow by 19% over the next ten years.[20] The growth in the sector has increased the interest in many of the occupational hazards that salon workers face. However, the literature is sparse, and no systematic reviews exist that synthesize data airborne occupational exposures to nail salon products. Therefore, this is an essential gap in the literature that should be filled in order to have a comprehensive understanding of the status quo in terms of exposure.

2.1.1 Exposure

Nail salon workers use a variety of products that contain chemicals, including volatile organic compounds (VOCs), e.g., toluene and formaldehyde, semi-volatile organic compounds (SVOCs), e.g., dibutyl phthalate, and particulate matter (PM), e.g., respirable dust.[21–26] Exposure to these chemicals has been linked to one or more of the following adverse health outcomes: reproductive effects, neuropsychological symptoms, cancers, or respiratory effects. The dominant route of exposure is mainly through inhalation, although dermal exposure through direct contact and vapor deposition can also increase body burden.[21]

2.1.2 Evidence of health impacts

A growing body of evidence, particularly over the past decade, has explored the associations between exposure to nail products and adverse health effects. Benzene, toluene, ethylbenzene, and xylene (BTEX) are often found in petroleum products and used as solvents in nail polish and thinners.[27] Benzene is a potent carcinogen that is "known" human carcinogen linked to acute myeloid leukemia and non-Hodgkin's lymphoma.[28] Toluene found in nail polish and nail glues can cause adverse reproductive health outcomes in women leading to spontaneous abortions[29]. Long-term exposure toluene exposure can also cause damage to the nervous system; while short-term exposure can irritate the mucous membrane[30] Toluene and xylene may also cause muscle fatigue, insomnia, and liver and kidney damage.[31] Formaldehyde, another common nail polish ingredient, can cause pneumonia and bronchitis over short duration exposures [32] It is also a skin sensitizer linked to lung and nasopharyngeal cancer and has been shown to cause squamous cell cancer in animal tests.[33] Toluene and formaldehyde, along with dibutyl phthalate, are referred to as the "toxic trio" because of their known adverse health impacts.[34]

Another group of chemicals of interest are sensitizers, including methyl methacrylate (MMA) and ethyl methacrylate (EMA), which are found in artificial acrylic nails, gels, and powders. They can cause respiratory sensitization leading to asthma, paresthesia, endocrine disruption, contact dermatitis, and respiratory tract inflammation.[35–37]

Of all the health acute health effects, irritation of the eyes, nose, throat, and skin are the most common. Different types of acetates (e.g., ethyl acetate, butyl acetate) and alcohols (e.g., isopropyl alcohol, ethyl alcohol) which are found in nail polish act as irritants and lead to central nervous system (CNS) syndrome at high exposures.[38–41] There are many other chemicals that nail salon workers are exposed to that have incomplete toxicological profiles. Therefore, workers do not have the full scope of all the hazards they face from chemical and biological exposures in the workplace.

Systematic reviews are a useful tool for an unbiased appraisal of the body of evidence on a specific topic or field of study, informing policy.[42] Over the past few years, efforts have been made to develop systematic review methodologies that can specifically address environmental and occupational health issues and reach hazard conclusions. The National Toxicology Program (NTP) and the National Institute of Environmental Health Sciences (NIEHS) within the Office of Health Assessment and Translation office (OHAT) designed a set of operating protocols called the OHAT Approach for Systematic Review and Evidence Integration.[43] The OHAT method is conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[44] and uses a 7-step framework. The framework's final step is to integrate the evidence collected during the review to develop hazard identification conclusions. In this study, the OHAT approach is used to characterize the occupational exposure to chemicals used in nail salons in the United States and to explore adverse health outcomes in nail salon workers.

2.1.3 Research objectives and strategy

The objective of this systematic review of the literature was to synthesize the body of literature on nail salon worker's occupational exposure to airborne chemicals in the United States between the years 1900 to 2020. Due to the differences amongst countries in allowable nail products as well as training and licensing requirements for nail salon workers, the review was limited to the United States, where the reviewers are based. The secondary objective was to determine the association between occupational exposure to airborne nail salon chemicals and defined health outcomes in nail salon workers in the United States. Many of the chemicals used in nail salons have been singularly recognized and explored in the literature for their toxic potential to harm human health. This systematic review provides concise yet detailed public health information for workers, employers, public health professionals, and organizations to affirm to the need to reduce exposure to these chemicals.

2.1.4 Specific Aims

Objective 1

- Identify published exposure assessment results (air sampling only) from nail salons located in the United States.
- Extract and summarize the available air monitoring data and compare studies.
- Identify limitations in the studies and gaps in the literature.

Objective 2

- Identify the literature reporting any adverse health effects from occupational exposure to chemicals used in nail salons.
- Extract and synthesize data for risk of bias assessment.
- Rate the confidence in the body of evidence for adverse health outcomes.

2.2 Methods

2.2.1 Problem Formulation and Protocol Development

The researcher conducted the problem formulation activities for this systematic review, and they were agreed upon with a second reviewer. Guidance for the methodology used to conduct this review was obtained from the OHAT Handbook for Conducting a Literature-Based Health Assessment using the OHAT Approach for Systematic Review and Evidence Integration. All aspects of this methodology were agreed upon with the second reviewer.

2.2.1.1 PECO Statement

A PECO (Population, Exposure, Comparators, and Outcomes) statement was developed to guide the identification of search terms and the inclusion and exclusion criteria for the research objective and is presented in Table 2.1.

Table 2-1 PECO Statement for Objective 1

Element	Type of Evidence
Population	Workers who are exposed to chemicals used in nail salon processes during their time of employment in the nail salons. Titles may include manager, supervisor, manicurist, pedicurist, and nail technician.
Exposure	Nail salon chemicals such as acrylic gels and powders, nail polish and nail polish removers and thinners, fingernail glue, and nail hardeners.
Comparators	Nail salon workers who have had no or low exposures (below detectable limits or OELs) to nail salon chemicals in the workplace.
Outcomes	*Primary health outcomes*: any adverse health effects, including reproductive and developmental toxicity, cancer, acute effects, immune system effects, liver and kidney toxicity, neurological effects. *Secondary health outcomes*: observational endpoints of physiological function such as oxidative stress bioassays, liver, and kidney function markers. *No health outcome*: Studies that conducted environmental monitoring but did not report health outcomes will be included as well.

For the evaluation of adverse health effects associated with occupational exposure to airborne nail salon products, the main focus was clinical diseases and symptoms of all major body systems and evidence of genetic toxicity. Unfortunately, no clinical studies were included in this systematic review as they did not meet the PECO criteria. For objective 2, the level of environmental contamination (air) reported in various working environments where nail salon chemicals are used was summarized. A summary was also done of the associated adverse health effects in nail salon workers, potentially from occupational exposures to nail salon chemicals.

2.2.1.2 Literature search

Four electronic databases were searched using a unique search strategy designed for each database: PubMed, Web of Science, Scopus, and Embase. The search terms for PubMed are reported in Appendix A. Only articles published in the English language were included; there were no publication year limits, and the databases were searched between October 25, 2020, with a last updated search on November 11. The reference lists of all included studies can be found in Appendix B.

2.2.2 Study selection

2.2.2.1 Evidence selection criteria

To be eligible for inclusion in the systematic review, studies needed to comply with the PECO statement's criteria above for objective one or contain relevant environmental monitoring in nail salons or biomonitoring assessment information collected from nail salon workers. The inclusion and exclusion criteria used to screen relevant studies and determine eligibility at both the title-and-abstract and full-text screening stages are summarized in Table 2.2.

2.2.2.2 Screening process

Articles retrieved from the literature search were screened for relevance and eligibility against the evidence selection criteria. Included articles were imported into Microsoft Excel and categorized by the database from which they were retrieved. References that were not excluded during the title and abstract review were next screened for eligibility during the full-text review phase. Following a full-text review, the remaining studies were included in the final review and used to evaluate the evidence presented.

Table 2-2 Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Participants/Population (human studies or experimental model systems)	
Studies in adult humans (age ≥18 years old) utilizing a cohort, cross-sectional, case-control study design, or case reports/series in the United States. Studies that conduct environmental monitoring assessments in nail salons in the United States.	Non-human animals, including laboratory animal studies or pets
	In silico studies or in vitro models utilizing organs, tissues, cell lines, or cellular components
Exposure	
Occupational exposure to nail salon chemicals, e.g., nail polish, nail polish removers, acrylic dipping powders, gel nail polish, and hardener	Chemicals not used in nail salon processes: Occupational exposure to other hazardous drugs or workplace exposures (e.g., chlorine and other cleaning products, or viruses)
Inhalation and dermal exposure occurring via occupational exposure	
Comparators	
Humans exposed to lower levels (or no exposure/exposure below detection levels) of chemicals used in nail salons	None
Outcomes	
Primary health outcomes: any adverse health effects, including reproductive and developmental toxicity, cancer, acute effects, immune system effects, liver and kidney toxicity, neurological effects.	There are no exclusion criteria for outcomes. All health outcomes are listed under inclusion criteria.
Secondary health outcomes: observational endpoints of physiological function such as oxidative stress bioassays, liver and kidney function markers.	
Publications	
Studies must contain original data and must be peer-reviewed	Articles with no original data (e.g., editorials, reviews)
English and non-English language studies	Non-peer reviewed articles (e.g., conference abstracts or other studies published in abstract form only, grant awards, and theses/dissertations)
	Retracted articles

2.2.2.3 Data Extraction

Extraction Process

Data were extracted from included studies and checked for completeness and accuracy. Any discrepancies regarding an included study were resolved by discussion with the second reviewer. Exposure measurements were retrieved from all included articles. Units were standardized to ensure uniformity in comparisons, specifically changing $\mu g/m^3$ or mg/m^3 to ppm for vapors. Extracted airborne chemical data measurements in environmental monitoring studies were all reported as mean or medians or both, and ranges for individual chemicals. Left-censored data were replaced with the method detection limit. All extracted data were stored in an Excel workbook for reference.

2.2.2.4 Quality Assessment of Individual Studies

A Risk-of-bias assessment was conducted for all the included studies using a tool developed by OHAT. The OHAT tool has specifically customized questions vital in assessing the study's internal validity, including categories to assess selection bias and confounding, performance and detection bias, and bias from loss to follow-up. All articles were independently assessed and then received an overall bias rating using the OHAT tool depicted in Figure 2.1. Each internal validity criteria were ranked on a continuum with the highest level of validity, scoring "definitely low risk of bias" to scoring the lowest level of validity with "definitely high risk of bias." Risk-of-bias assessments for confounding, exposure characterization, and outcome assessment were considered especially critical. Articles that conducted biomonitoring were subjected to additional assessments of validity. Participants' selection, use of the best available industry-recommended air sampling methods, and laboratory analytical methods were especially heavily scrutinized. The overall body of evidence was determined based on the individual article assessments to address objectives 1 and 2.

Symbol	Description
++	***Definitely Low*** *risk of bias*: There is direct evidence of low risk of bias practices (May include specific examples of relevant low risk of bias practices)
+	***Probably Low*** *risk of bias*: There is indirect evidence of low risk of bias practices, **OR** it is deemed that deviations from low risk of bias practices for these criteria during the study would not appreciably bias results, including consideration of direction and magnitude of bias.
- NR	***Probably High*** *risk of bias*: There is indirect evidence of high risk of bias practices, **OR** there is insufficient information (e.g., not reported or "N.R.") provided about relevant risk of bias practices.
--	***Definitely High*** *risk of bias*: There is direct evidence of high risk of bias practices (May include specific examples of relevant high risk of bias practices).

Figure 2.1 Risk-of-bias assessment rating for individual studies.

2.3 Results and Evidence Synthesis

2.3.1 Literature search results

A search of the electronic databases retrieved 2,950 unique references. No additional references were identified from published reviews of reference lists of the included studies. Two thousand nine hundred six studies were excluded during the title and abstract screening phase, and 27 were excluded during the full-text review phase. The screening results are outlined in a study selection flow diagram in Figure 2.2, along with justifications for study exclusion. Of the 17 studies included in the full-text review, four studies reported primary or secondary health outcomes. The 17 studies for inclusion measured airborne exposure to VOCs and particulates among nail salon workers.

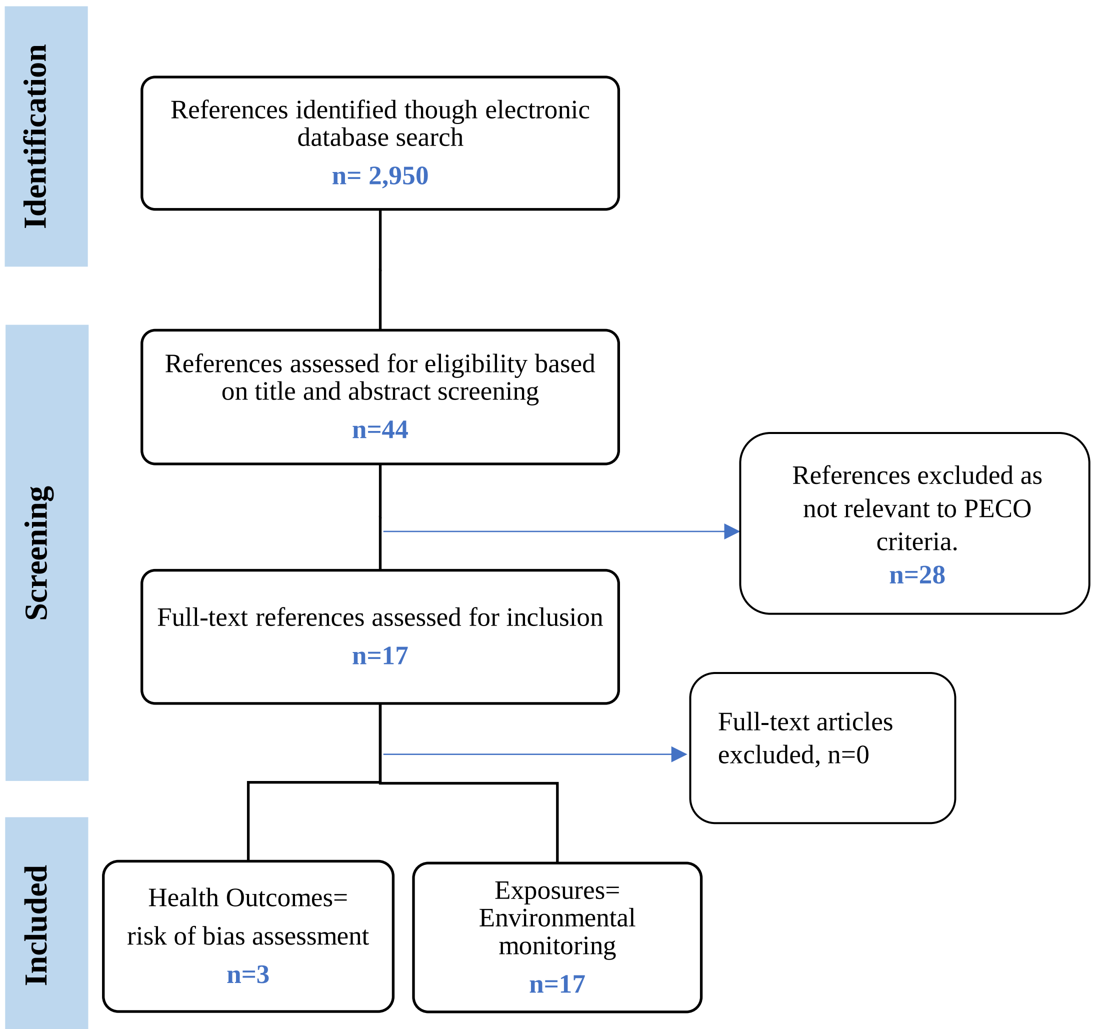

Figure 2.2 Study selection flow chart

2.3.2 Risk-of bias-assessment

The criteria used to assess biases were recruitment and selection of study participants, method sensitivity (detection/quantification limits), exposure variability and exposure characterization, variation in exposure levels across groups (comparable groups), adequacy of indirect measures to characterize exposure (e.g., questionnaires, chemical proxy measurements), confounding, and health outcome assessment. Health outcome assessment was still used as a measure even though only four included studies had measurable health outcomes. This decision is in agreement with the OHAT guidelines handbook.[43] No studies were excluded based on concerns of biases.

Overall, two studies had a low risk of bias, and 14 had a moderate risk of bias, primarily based on sample selection and recruitment. The two studies with a low risk of bias selected participants randomly for participation in an intervention study to reduce occupational exposure to nail salon chemicals. There were comparison groups with varying exposures, which reduced the risk of bias.

2.3.3 Exposure Measurements

Quantitative data extracted from the included studies are summarized in table 2.3. The central tendency measures are reported based on published data and included either the mean or median. The range of measurements reported in Table 2.3 includes combinations of the area and personal (breathing zone) measurements for some articles. Generally, personal sample concentrations exceeded area sample concentrations in studies that measured both. Zhong et al. (2019) reported statistically significant differences between area and personal concentrations for 7 out of 11 chemicals. Ceballos et al. (2019) also compared personal and area samples and found that 8 of 12 personal sample concentrations were higher than area samples, but only three were statistically significantly different. The area samples for benzene and ethyl methacrylate were higher than the personal samples, and the difference was statistically significant. Across all studies acrylates and VOCs were the most detected, with over 70% of the included studies reporting concentrations. Three intervention studies explored changes in concentrations of toluene, MMA, and TVOCs, before and after the workers received training. Of all the recorded measurements from all 17 papers combined, six individual samples exceeded one or more OELs (TLV, PEL, REL, STEL).

2.3.3.1 BTEX

Eleven out of 17 studies measured one or more BTEX chemicals. Sample measurements were generally low, and many samples were below the limit of detection (LOD). Alaves et al. (2013) recorded a single, 8-hr TWA area sample of benzene that exceeded the TLV value threefold. Lamplugh et al. (2019) documented BTEX concentrations in Colorado nail salons that were several magnitudes higher than those documented by Ceballos et al. (2019) in the Boston metropolitan area. For example, the upper limit of benzene measurements in Colorado was 0.12ppm compared to 0.0001ppm in Boston, the upper limit for toluene was 0.22ppm in Colorado but 0.022ppm in Boston. Both studies included salons with similar volumes and the same average numbers of nail stations and mechanical ventilation types. However, Colorado's salons were located next to major highways and nearby to a gas station, which may account for the elevated measurements.[45] However, the authors did not account for this potential bias in their article.

2.3.3.2 Acrylates

Thirteen of out 17 studies measured one or more acrylate. The most common was MMA followed by EMA, and 1 study measured isobutyl methacrylate. Most studies reported MMA substantially under the OELs, except for Ma et al. (2019), where the range of personal air measurements for 4-8-hr sampling periods of MMA was 0.049-941.25ppm. The maximum measurement of 941.25ppm was recorded in a single salon and represented 1 out of 100 samples taken across 26 nail salons. Two other measurements of 18.95 ppm and 21.52 ppm of MMA were recorded in different salons, but all other measurements were below 0.1ppm. Quach et al. (2013) also recorded one outlier measurement of 544.94ppm due to possible contamination of the sample. Five studies measured EMA with concentrations ranging from 0.00001-18.0ppm. Three studies with the highest concentrations, ranging from 9.0-18.0ppm, were published between 1986 and 1997. The highest EMA measurement post-2000 was 1.48ppm.

2.3.3.3 VOCs

Most studies included a variety of common VOCs in their analysis, such as acetones and alcohols, or reported a compound measurement in the form of TVOCs. Six studies reported TVOCs measurements above the LEED industry benchmark level of 0.12ppm (500 µg/m^3)[46]. Harrichandra et al. (2020) recorded a range of daily TVOC averages from 0.09 to 85 ppm.[47] These were area measurements collected using a photoionization detector (PID) which is non-specific and would have detected all VOCs, including those not produced by nail salon product. The full range of TVOC measurements by Quach et al. (2018) exceeded the benchmark value. Alaves et al. (2013) recorded 8-hour time-weighted average (TWA) area samples for isopropyl alcohol above the TLV, with a maximum measurement of 1300ppm.

2.3.3.4 Other Airborne Contaminants

Particulate matter

Goldin et al. (2014) measured $PM_{2.5}$ and recorded a range of 6.1- 56 µg/m^3, with the upper end being approximately 1.5 times the 24-hour limit, but 50 times lower than OSHA PEL of 5000 µg/m^3 for respirable particulates. Respirable particulates includes particles size of 4µm or less.[48] Hiipakka and Samimi (1987) measured respirable nuisance dust and total dust, with the upper ranges being 3.5 fold and 1.5 fold, respectively, below the OSHA PEL. Carbon dioxide was often used as a proxy for ventilation rates.

Carbon dioxide

The highest documented measurement of CO_2 was 2200ppm[49] recorded in one salon that had an average CO_2 concentration of 1780ppm during service hours over three days. These concentrations are an indication of contaminant buildup likely due to poor ventilation. At this level, the air may feel uncomfortable but generally not associated with complaints of health symptoms.[50] Acetates were measured in 7 out of 17 studies.

Acetates

Ethyl acetate and butyl acetate were the most frequently measured VOCs in the nail salons. Quach et al. (2011) recorded a maximum measurement of 5.50 ppm for ethyl acetate, well below the OSHA PEL of 400 ppm. Craig et al. (2019) measured exposure to phthalates and organophosphate esters through passive air sampling and urine samples biological monitoring. Most of the samples were below the LOD. Dibutyl phthalate (DBP), one of the “toxic trio” of nail salon chemicals did not exceed its TLV of 0.44pm, with only 11% of measurements above the LOD. Triphenyl phosphate (TPHP) was recorded below the TLV of 3 mg/m^3, but 89% of samples were above the LOD.

2.3.4 Risk of bias assessment

Overall, 14 out of the 17 studies all ranked as having a moderate to high risk of bias in the categories of method sensitivity (detection/ quantification limits), exposure variability and exposure characterization, variation in exposure levels across groups (comparable groups), and adequacy of indirect measures to characterize exposure. Generally, there was a high level of confidence in the research methods to quantify exposure. Almost all the studies used validated methodologies to assess exposures, including analytical methods and instrumentation.

Table 2-3 Extracted data from all included studies.

Article	Sample size	Analyte	Mean (ppm)	Median (ppm)	Range (ppm)
Alaves et al., 2013	14	Acetone	6.1		1.6-13
	14	Toluene	0.098		0.014-0.31
	14	Ethyl acetate	0.37		0.05-2.0
	14	Benzene	0.00044		0-1.5*
	14	Isopropyl alcohol	0.77		260-1300*
	14	Formaldehyde	0.017		0.0009-0.032
	14	MMA	0.87		>0.34-4.1
Ceballos et al., 2019	18	Benzene		0.00075	<0.00005-0.0001
	18	Toluene		0.00557	0.001-0.022
	18	Ethylbenzene		0.00008	<0.00004-0.0005
	18	o-Xylene		0.00012	<0.0001-0.001
	18	m,p-Xylene		0.0001	<0.0001-0.002
	18	EMA		0.0500	<0.0001-1.48
	18	MMA		0.0500	<0.0001-0.63
	18	Ethyl Acetate		0.1800	0.04-0.78
	18	Styrene		0.00009	<0.00003-0.0001
	18	p-Isopropyltoluene		0.00009	<0.00003-0.06
	18	d-Limonene		0.001	0.001-0.03
	18	Carbon tetrachloride		0.00005	0.00001-0.0001
Craig et al., 2019 ♣		*Phthalates*****			
	18	BBzP		<0.0067	<0.0067 – 0.0051
	18	DBP		<1.12	<0.048– 0.179
	18	DiBP		<0.018	<0.018– 0.013
	18	DEP		<0.0315	<0.0315 – 0.0879
	18	DMP		<0.0018	<0.0018 – 0.00053
	18	DEHP		<0.0172	4.5 -0.397
	18	DiNP		0.01975	<0.0172 - 0.429
		Phthalate Alternatives			
	18	DEHA		0.000355	<0.0018 - 0.152
	18	TOTM		0.00022	0.03 – 0.0448
	18	DEHTP		0.02135	1.9 - 0.529
		Organophosphate Esters			
	18	TCIPP		<0.00445	<0.0067 – 0.0332
	18	TCEP		0.0316	<0.0316– 0.0062
	18	TDCIPP		<0.00112	<0.0012 – 0.0046
	18	TPHP		0.0229	<0.0061– 0.134
Estill et al., 2020	12	Triphenyl phosphate		0.000001	2.94-21.9 (ng/m^3)
Froines & Garabrandt, 1986	25	MMA		18.5	2.1-47.6
	15	EMA		9.80*	2.4-18.0
	5	IMA		5.00	0.9-7.7
Garcia et al., 2015		*Pre-intervention****			
	24	Toluene	1.23		0.04-0.17
	24	MMA	1.12		0.02-6.8
	24	TVOCs	2.35		0.33-4.00
		Post-intervention			
	24	Toluene	0.07		0.019-0.19
	24	MMA	2.30		0.02-17.07
	24	TVOCs	0.85		0.26-2.44

Goldin et al., 2014	21 21 21	TVOCs CO_2 $PM_{2.5}$		4.8 1100 18 µg/m^3	0.061-38 660-1600 6.1-56 µg/m^3
Harrichandra et al., 2020	33 33 30 30 30	TVOCs CO_2 Toluene MMA Ethyl acetate	29.00 1070 0.06 0.12 0.69		0.09-85 460-2200 0.03-0.18 0.04–1.3 0.03-2.8
Hiipakka & Samimi, 1987	17 17 17 17 16 16	Toluene Isopropyl alcohol Butyl acetate EMA Respirable nuisance dust Total nuisance dust	0.80 15.60 0.40 4.50 0.90 1.40		0.1-2.0 <0.1-54.1 <0.1-2.3 <0.1-17.0 0.2-3.2 mg/ m^3 0.3-4.3 mg/ m^3
Lamplugh et al., 2019	36 36 36 36 36 54 36 36 36 36 36	Acetone Methyl ethyl ketone Ethyl acetate MMA N-butyl acetate formaldehyde Benzene Toluene Ethylbenzene Xylene Total BTEX		14.00 0.00 0.27 0.00 0.10 0.006 0.00164 0.0614 0.0006 0.00216	8.0-30 0-0.13 0.21-0.55 0.00-0.52 0.04-0.28 0.004-0.02 0.001-0.12 0.01-0.22 0.0004-0.002 0.001-0.01 73.7-873 µg/m^3
Ma et al, 2019	100 100 100	Acetone MMA Toluene	18.5 39.5 0.1		3.30-58.47 0.049-941.25$^\alpha$ 0.06-0.24
Pavilonis et al, 2018	20 20	TVOCs CO_2	12.0 800	4.0 720.0	0.035-67 400-1800
Quach et al., 2011 ♣	169 167 3 3 3 3 169	Ethyl acetate Isopropyl acetate Butyl acetate Acetone Isopropyl alcohol MMA Toluene	0.53** 0.04 0.03 3.1 0.82 0.54 0.15**		0.02–5.50 0.02–0.15 0.01-0.06 0.31-6.60 0.06-2.0 0.12-1.30 0.01–1.0
Quach et al., 2013 ♣	 70 70 70 70 70 70	*Pre-intervention**** Toluene MMA TVOCs *Post-intervention* Toluene MMA TVOCs	 0.06 69.67 6.63 0.10 19.70 4.80		 0.037-0.097 0.06-544.94$^\alpha$ 03.32-14.17 0.019-0.19 0.02-17.07 0.26-2.44

Quach et al, 2018 ♣	198 198 198	MMA Toluene TVOCs	1.15 0.021 4.67*		0.69-1.68 0.000013-0.00008 3.53-6.49
Spencer et al., 1997	36	EMA	2.78		0.03-9.4
Zhong et al., 2019	68 68 68 68 68 68 68 68 68 68 34 68	Ethyl acetate Isopropyl acetate n-propyl acetate n-butyl acetate MMA EMA N-heptane Benzene Toluene d-Limonene Formaldehyde TVOCs	0.44 0.05 0.013 0.099 1.02 0.015 0.019 0.0011 0.025 0.004 0.008 1.62		0.02-2.68 <0.001-0.03 <0.001-0.07 0.004-0.95 0.0006-8.79 0.00011-0.41 <0.00005-0.046 <0.00003-0.009 <0.00002-0.17 <0.00002-0.05 <0.004-0.03 0.07-10.19

Notes

<- indicates minimum values were below the limit of detection
a- Isobutyl methacrylate
b- Values are ranges of means of measurements across all nail salons
α- Upper limit was determined to be an outlier for MMA
♣- Intervention studies
**- Values exceeded one or more OELs*
***- Weighted mean of personal and area air samples*
****-Measurements are means of means*
*****- acronyms are defined in [Appendix C].*

2.4 Discussion

This systematic review of the literature revealed that nail salon workers are exposed to many chemicals at varying concentrations. The studies included in this systematic review span approximately 35 years, with 80% of the research being conducted in the last decade. Comparatively, concentrations for some of these airborne chemicals have decreased markedly, indicating that regulations to reduce some exposures have had an effect. Consistently, factors such as types and number of services offered each day and lack of ventilation systems operation positively correlate with nail salons' airborne chemical concentrations. The distance between contaminant source and sampler and the use of ventilation could explain the differences between personal and area sampling. When workers use chemicals at their nail stations, the greatest concentrations are expected to be in the breathing zone, e.g., opening a bottle of nail polish with highly volatile chemicals will release a high concentration directly into the worker's breathing zone. Having local exhaust ventilation at the workstation will reduce this exposure faster than general exhaust ventilation. For these reasons, in occupational settings, personal sampling may offer a more accurate depiction of exposure. Some studies have demonstrated that training nail salon workers and owners about proper engineering and administrative controls and substituting harmful chemicals for safer ones have reduced exposure.[25,51] There is a lack of epidemiological studies in the literature investigating the effectiveness of interventions to reduce occupational exposure to chemicals in nail salons.

2.4.1 Health Effects associated with nail salon chemicals.

2.4.1.1 Sensitizing agents

The use of 100% MMA was banned in the United States in the 1970s after being linked to fingernail damage and dermatitis, but MMA compounds are still used.[52] There has been a general decline in airborne concentrations of MMA and EMA concentrations found in nail salons over the past 35 years. However, contact allergies and sensitization are still prevalent among nail salon technicians even when exposed to low levels.[53–55] In a 7-year study on allergic contact dermatitis caused by acrylates, beauty technicians working with artificial nails represented 80% of the cases with an allergic reaction to methacrylates.[56] There is a continued debate in the scientific literature about whether a threshold can be determined for chemical allergies.[57,58] This is attributed to a complex interaction of the route of exposure, the specific sensitizer, and the exposed individual's inflammatory response.[57] Some studies suggest that DBP and TPHP might also have sensitizing properties, but the evidence is inconclusive.[59,60]

2.4.1.2 Carcinogens

Several carcinogens were identified in the 17 studies, including benzene, carbon tetrachloride, and formaldehyde. One sample measured benzene concentrations three times greater than the TLV, which was likely the result of no direct exhaust ventilation recorded for that salon. While both benzene and formaldehyde were generally below their respective OELS, there is a concern for long-term exposure to these carcinogens even in low doses and the potential for synergistic effects when combined with other chemicals used in nail products.[61,62] Carbon tetrachloride is another carcinogen detected in airborne samples. Airborne concentrations of the identified carcinogens have not varied much over the past decade. However, it is still worthwhile for regulatory agencies to implement measures to either eliminate these chemicals from nail products.

2.4.1.3 Irritants

Several nail salon chemicals such as acetates, alcohols, toluene, and phthalates are known to irritate the eyes, nose, throat, and skin. Although most studies reported irritant concentrations well below the OELs, workers still presented with symptoms typical of inhalation and dermal exposure to these chemicals. Quach et al. (2011) did not measure a single chemical that exceeded the OEL, yet more than 30% of workers reported an adverse health outcome, with 26% reporting nose, throat, lung, skin, or eye irritation.[26] Ma et al. (2019) also reported low concentrations of irritants, but almost 52% of workers said they experienced nose, throat, eye, and skin irritation. Some stated that their irritation began when they joined the nail salon industry or worsened during their time in the industry.[63] These results indicate that combined exposure to different chemicals, even at low levels, may have adverse health impacts and could become chronic conditions if the exposures are not reduced further.

2.4.2 Epidemiological Evidence: Linking exposure and health outcomes.

There is no significant level of evidence in this review that suggests that occupational exposure to airborne nail salon chemicals or by-products of those chemicals, in studies in the United States, cause any health effects in the study populations. However, this is not an indication that these chemicals and by-products are not harmful. Many of the individual chemicals have been proven to be harmful in animal studies[36,37,64] and some epidemiological studies.[65–67] This review identified several studies that recorded health symptoms amongst nail salon workers. However, the methodologies did not allow for conclusive associations between occupational exposure and health outcome. Three epidemiological studies evaluated interventions on reducing occupational exposure to airborne nail salon chemicals, but these studies did not measure the association with health effects.[25,68,69] Despite the existence of national guidelines or general industry recommendations for safe thresholds of exposure, there was not substantial compliance with the use of personal protective equipment or engineering controls to reduce occupational exposure for nail salon workers.[25,51,68]

2.4.2.1 Intervention studies: Health and safety training to reduce occupational exposure

The results from Garcia et al. (2015) suggested that the health and safety training was more successful in reducing toluene and TVOCs concentrations but not MMA exposure. Quach et al. (2103) found distinct results, where the average concentration of toluene increased, but TVOCs and MMA were reduced post-intervention. There was a lower risk of bias in selecting and comparing the intervention and control groups in this study due to the randomization of sampling. Participants were matched very closely in the intervention and control groups according to demographics, strengthening the comparison. Since randomized controlled trials (RCTs) are the gold standard for epidemiological study designs, this well-conducted study has the least risk of bias in this systematic review. The findings that the interventions reduced occupational exposure to one or more chemicals should be considered valid. Other training interventions have proved unsuccessful in reducing worker exposure to chemicals, including the randomized control trial by Quach et al. (2018). They found that the intervention group had statistically significantly greater odds of using proper ventilation, opting for less toxic nail polishes, and choosing the correct glove type for the chemicals being handled,[69]but this did not translate into improved air quality. Measurement error may have occurred due to self-reporting of worker practices. The inconsistent use of ventilation in the salons may also be a factor for these findings and explain differences in chemical concentrations during pre-and post-intervention. Additionally, all samples collected in the Quach et al. (2018) study were personal air samples which are subject to greater interpersonal variability.[70]

2.4.3 Limitations

Although this systematic review followed a rigorous protocol by OHAT standards and guidelines, there are a few important limitations in the study designs. Though not explicitly stated in the two intervention studies, it is suspected that participants were not randomly chosen for all the intervention or all the control groups. Additionally, all the included environmental monitoring studies utilized convenience sampling for participating nail salons and workers. Therefore, the generalizations that are made from the findings can only be applied to the sampled population.[71] Randomization is done to reduce biases in selecting participants so that the outcome of an intervention cannot be predicted.[72] If the participants were not selected and volunteered, this potentially introduces volunteer bias into the studies and reduces the study's internal validity.[73] Another limitation is excluding studies that may have presented more evidence for the association between the documented chemicals and observed health effects. There were only three included epidemiological studies in the full body of evidence reviewed. However, there is a high level of confidence that the environmental monitoring data reported by the included studies in this systematic review represent an accurate depiction of the types and concentrations of chemicals that nail salon workers are exposed to in the occupational setting.

2.5 Conclusions

Overall, few chemical measurements from the included studies exceeded occupational exposure limits. However, it is posited that even low concentrations of a mixture of VOCs can have an additive or synergistic effect but is not well documented and should be explored. Although many harmful chemicals are used in nail salons, only a few are investigated in the included studies. These research gaps present a timely opportunity for researchers to expand their studies' scope to explore less frequently studied chemicals that may have greater adverse health outcomes at lower concentrations. Generally, it appears that workers are not overexposed, but with the small sample sizes in most studies, it may not be an accurate conclusion. The number and duration of air samples collected should increase and comprise both personal and area samples for a more accurate representation of occupational exposure. New studies should be guided by walkthrough audits that assess chemical hazards in advance so sampling could be strategic and result in actionable steps to reduce exposure.

All the included studies have investigated airborne exposures to chemicals present in nail salon products. However, none have conclusively associated health symptoms with occupational exposures, although many of these individual chemicals have been shown to affect human health adversely. There is a need to investigate these occupational exposures using robust longitudinal epidemiological study designs. The intervention studies indicated that providing occupational health and safety training to workers may be an option to encourage safer workplace behaviors and practices. Overall, the OHAT model allowed a comprehensive review of the literature, particularly to characterize nail salon hazards investigated in environmental monitoring studies which are not often included in traditional systematic reviews.

2.6 References

1. U.S. Department of Labor, Bureau of Labor Statistics. Occupational Outlook Handbook, Manicurists and Pedicurists. Published September 4, 2019. Accessed January 5, 2020. https://www.bls.gov/ooh/personal-care-and-service/manicurists-and-pedicurists.htm?view_full#tab-6
2. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Office of Administration and Resource Management. *Protecting the Health of Nail Salon Workers*. U.S. Environmental Protection Agency; 2004.
3. US Department of Labor, Occupational Safety and Health Administration (OSHA). *Stay Healthy and Safe While Giving Manicures and Pedicures: A Guide for Nail Salon Workers.* American Psychological Association (APA); 2012.
4. US Department of Labor, Division of Occupational Employment Statistics. *Occupational Employment and Wages, May 2018: 39-5092 Manicurists and Pedicurists*.; 2019. https://www.bls.gov/oes/current/oes395092.htm#(1)
5. Nir SM. Perfect Nails, Poisoned Workers. *The New York Times*. https://www.nytimes.com/2015/05/11/nyregion/nail-salon-workers-in-nyc-face-hazardous-chemicals.html. Published May 13, 2015. Accessed June 12, 2019.
6. Roelofs C, Azaroff LS, Holcroft C, Nguyen H, Doan T. Results from a Community-based Occupational Health Survey of Vietnamese-American Nail Salon Workers. *J Immigrant Minority Health*. 2008;10(4):353-361. doi:10.1007/s10903-007-9084-4
7. Quach T, Gunier R, Tran A, et al. Characterizing Workplace Exposures in Vietnamese Women Working in California Nail Salons. *American Journal of Public Health*. 2011;101(S1):S271-S276. doi:10.2105/ajph.2010.300099
8. Ma GX, Wei Z, Husni R, et al. Characterizing Occupational Health Risks and Chemical Exposures Among Asian Nail Salon Workers on the East Coast of the United States. *J Community Health*. Published online July 11, 2019. doi:10.1007/s10900-019-00702-0
9. Pavilonis B, Roelofs C, Blair C. Assessing indoor air quality in New York City nail salons. *Journal of Occupational and Environmental Hygiene*. 2018;15(5):422-429. doi:10.1080/15459624.2018.1447117
10. Roelofs C, Do T. Exposure Assessment in Nail Salons: An Indoor Air Approach. *ISRN Public Health*. 2012;2012:1-7. doi:10.5402/2012/962014
11. National Institute for Occupational Safety and Health (NIOSH). *NIOSH Pocket Guide to Chemical Hazards: Isopropyl Acetate*.; 2015. http://www.cdc.gov/niosh/npg/npgd0358.html.
12. ATSDR (Agency for Toxic Substances and Disease Registry). *Toxicological Profile for Toluene*.; 2000. http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=161&tid=29.
13. ATSDR (Agency for Toxic Substances and Disease Registry). *Toxicological Profile for Acetone*.; 1994. http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=5&tid=1.

14. OSHA (Occupational Safety and Health Administration). *Stay Healthy and Safe While Giving Manicures and Pedicures: A Guide for Nail Salon Workers*.; 2012. https://www.osha.gov/Publications/3542nail-salon-workers-guide.pdf.
15. Freeman S, Lee M-S, Gudmundsen K. Adverse contact reactions to sculptured acrylic nails: 4 case reports and a literature review. *Contact Dermatitis*. 1995;33(6):381-385. doi:10.1111/j.1600-0536.1995.tb02071.x
16. Guin JD, Baas K, Nelson-Adesokan P. Contact sensitization to cyanoacrylate adhesive as a cause of severe onychodystrophy. *International Journal of Dermatology*. 1998;37(1):31-36. doi:10.1046/j.1365-4362.1998.00252.x
17. Baran RL, Schibli H. Permanent Paresthesia to Sculptured Nails: A Distressing Problem. *Dermatologic Clinics*. 1990;8(1):139-142. doi:10.1016/S0733-8635(18)30538-2
18. US EPA IRIS (United States Environmental Protection Agency Integrated Risk, Information System). *Toxicological Review of Methyl Methacrylate (CAS No. 80-62-6)*.; 1998. http://www.epa.gov/iris/subst/1000.htm.
19. World Health Organization (WHO). *Concise International Chemical Assessment Document 4. Methyl Methacrylate*.; 1998. http://www.who.int/ipcs/publications/cicad/en/cicad04.pdf.
20. U.S. Bureau of Labor Statistics. May 2018 OES Industry-Specific Occupational Employment and Wage Estimates. Published April 2, 2019. Accessed February 25, 2021. https://www.bls.gov/oes/2018/may/naics4_812100.htm
21. OSHA. Health Hazards in Nail Salons - Chemical Hazards. Accessed July 10, 2019. https://www.osha.gov/SLTC/nailsalons/chemicalhazards.html
22. Roelofs C, Do T. Exposure Assessment in Nail Salons: An Indoor Air Approach. ISRN Public Health. doi:https://doi.org/10.5402/2012/962014
23. Goldin LJ, Ansher L, Berlin A, et al. Indoor Air Quality Survey of Nail Salons in Boston. *JOURNAL OF IMMIGRANT AND MINORITY HEALTH*. 2014;16(3):508-514. doi:10.1007/s10903-013-9856-y
24. Alaves VM, Sleeth DK, Thiese MS, Larson RR. Characterization of indoor air contaminants in a randomly selected set of commercial nail salons in Salt Lake County, Utah, USA. *International Journal of Environmental Health Research*. 2013;23(5):419-433. doi:10.1080/09603123.2012.755152
25. Garcia E, Sharma S, Pierce M, et al. Evaluating a County-Based Healthy Nail Salon Recognition Program. *AMERICAN JOURNAL OF INDUSTRIAL MEDICINE*. 2015;58(2):193-202. doi:10.1002/ajim.22379
26. Quach T, Gunier R, Tran A, et al. Characterizing Workplace Exposures in Vietnamese Women Working in California Nail Salons. *AMERICAN JOURNAL OF PUBLIC HEALTH*. 2011;101(1):S271-S276. doi:10.2105/AJPH.2010.300099
27. Moradi M, Hopke P, Hadei M, et al. Exposure to BTEX in beauty salons: biomonitoring, urinary excretion, clinical symptoms, and health risk assessments. *ENVIRONMENTAL MONITORING AND ASSESSMENT*. 2019;191(5). doi:10.1007/s10661-019-7455-7
28. Abel EL, DiGiovanni J. Chapter 7 - Environmental Carcinogenesis. In: Mendelsohn J, Gray JW, Howley PM, Israel MA, Thompson CB, eds. *The Molecular Basis of Cancer (Fourth Edition)*. W.B. Saunders; 2015:103-128.e2. doi:10.1016/B978-1-4557-4066-6.00007-X
29. Ng TP, Foo SC, Yoong T. Risk of spontaneous abortion in workers exposed to toluene. *Occupational and Environmental Medicine*. 1992;49(11):804-808. doi:10.1136/oem.49.11.804

30. 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:10.1186/s12995-018-0213-x
31. Neghab M, Hosseinzadeh K, Hassanzadeh J. Early Liver and Kidney Dysfunction Associated with Occupational Exposure to Sub-Threshold Limit Value Levels of Benzene, Toluene, and Xylenes in Unleaded Petrol. *Saf Health Work*. 2015;6(4):312-316. doi:10.1016/j.shaw.2015.07.008
32. Fischer MH. The Toxic Effects of Formaldehyde and Formalin. *J Exp Med*. 1905;6(4-6):487-518. Accessed March 8, 2021. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2124506/
33. Bernstein RS, Stayner LT, Elliott LJ, Kimbrough R, Falk H, Blade L. Inhalation exposure to formaldehyde: an overview of its toxicology, epidemiology, monitoring, and control. *Am Ind Hyg Assoc J*. 1984;45(11):778-785. doi:10.1080/15298668491400601
34. Liou J, Porter C, Quach T. Policy Recommendations to Reduce Toxic Exposures for Nail Salon Workers. *AAPI Nexus Journal: Policy, Practice, and Community*. 2011;9:43-50. doi:10.36650/nexus9.1-2_43-50_LiouEtAl
35. IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. *(IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, No. 60.) Methyl Methacrylate.* International Agency for Research on Cancer; 1994. Accessed March 8, 2021. https://www.ncbi.nlm.nih.gov/books/NBK507525/
36. Aydin O, Attila G, Dogan A, Aydin MV, Canacankatan N, Kanik A. The effects of methyl methacrylate on nasal cavity, lung, and antioxidant system (an experimental inhalation study). *Toxicol Pathol*. 2002;30(3):350-356. doi:10.1080/01926230252929927
37. Blanchet LJ, Bowman DC, McReynolds HD. Effects of methyl methacrylate monomer vapors on respiration and circulation in unanesthetized rats. *J Prosthet Dent*. 1982;48(3):344-348. doi:10.1016/0022-3913(82)90026-9
38. Park S-A, Gwak S, Choi S. Assessment of occupational symptoms and chemical exposures for nail salon technicians in Daegu City, Korea. *J Prev Med Public Health*. 2014;47(3):169-176. doi:10.3961/jpmph.2014.47.3.169
39. Lens C, Malet G, Cupferman S. Antimicrobial activity of Butyl acetate, Ethyl acetate and Isopropyl alcohol on undesirable microorganisms in cosmetic products. *International Journal of Cosmetic Science*. 2016;38(5):476-480. doi:https://doi.org/10.1111/ics.12314
40. Hiipakka D, Samimi B. Exposure of acrylic fingernail sculptors to organic vapors and methacrylate dusts. *Am Ind Hyg Assoc J*. 1987;48(3):230-237. doi:10.1080/15298668791384670
41. Bowen SE, Balster RL. A Comparison of the Acute Behavioral Effects of Inhaled Amyl, Ethyl, and Butyl Acetate in Mice. *Toxicological Sciences*. 1997;35(2):189-196. doi:10.1093/toxsci/35.2.189
42. Gopalakrishnan S, Ganeshkumar P. Systematic Reviews and Meta-analysis: Understanding the Best Evidence in Primary Healthcare. *J Family Med Prim Care*. 2013;2(1):9-14. doi:10.4103/2249-4863.109934
43. Office of Health Assessment and Translation, National Institute of Environmental Health Sciences. *Handbook for Conducting Systematic Reviews for Health Effects Evaluations*. The National Toxicology Program; 2019. Accessed March 8, 2021. https://ntp.niehs.nih.gov/whatwestudy/assessments/noncancer/handbook/index.html

44. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med*. 2009;6(7):e1000097. doi:10.1371/journal.pmed.1000097
45. Lamplugh A, Harries M, Xiang F, Trinh J, Hecobian A, Montoya LD. Occupational exposure to volatile organic compounds and health risks in Colorado nail salons. *Environmental Pollution*. 2019;249:518-526. doi:10.1016/j.envpol.2019.03.086
46. U.S. Green Building Council. Indoor Environmental Quality Performance U.S. Green Building Council. Accessed March 7, 2021. https://www.usgbc.org/credits/existing-buildings-schools-existing-buildings-retail-existing-buildings-data-centers-5?return=/credits/Existing%20Buildings/v4.1/Indoor%20environmental%20quality
47. Harrichandra A, Roelofs C, Pavilonis B. Occupational Exposure and Ventilation Assessment in New York City Nail Salons. *Ann Work Expo Health*. 2020;64(5):468-478. doi:10.1093/annweh/wxaa035
48. NIOSH. Particulates-1988 OSHA PEL Project. Published September 28, 2011. Accessed March 5, 2021. https://www.cdc.gov/niosh/pel88/dusts.html
49. Pavilonis B, Roelofs C, Blair C. Assessing indoor air quality in New York City nail salons. *JOURNAL OF OCCUPATIONAL AND ENVIRONMENTAL HYGIENE*. 2018;15(5):422-429. doi:10.1080/15459624.2018.1447117
50. Bonino S. Carbon Dioxide Detection and Indoor Air Quality Control. Occupational Health & Safety. Published April 1, 2016. Accessed February 19, 2021. https://ohsonline.com/articles/2016/04/01/carbon-dioxide-detection-and-indoor-air-quality-control.aspx
51. Quach T, Varshavsky J, Von Behren J, et al. Reducing chemical exposures in nail salons through owner and worker trainings: an exploratory intervention study. *Am J Ind Med*. 2013;56(7):806-817. doi:10.1002/ajim.22146
52. Zhong L, Batterman S, Milando CW. VOC sources and exposures in nail salons: a pilot study in Michigan, USA. *INTERNATIONAL ARCHIVES OF OCCUPATIONAL AND ENVIRONMENTAL HEALTH*. 2019;92(1):141-153. doi:10.1007/s00420-018-1353-0
53. Chou M, Dhingra N, Strugar TL. Contact Sensitization to Allergens in Nail Cosmetics. *Dermatitis*. 2017;28(4):231-240. doi:10.1097/DER.0000000000000301
54. Horev L. Occupational Dermatitis in Nail Salon Workers. In: Tur E, Maibach HI, eds. *Gender and Dermatology*. Springer International Publishing; 2018:249-254. doi:10.1007/978-3-319-72156-9_20
55. LoSasso GL, Rapport LJ, Axelrod BN. Neuropsychological symptoms associated with low-level exposure to solvents and (meth)acrylates among nail technicians. *Neuropsychiatry Neuropsychol Behav Neurol*. 2001;14(3):183-189.
56. Ramos L, Cabral R, Gonçalo M. Allergic contact dermatitis caused by acrylates and methacrylates – a 7-year study. *Contact Dermatitis*. 2014;71(2):102-107. doi:https://doi.org/10.1111/cod.12266
57. Basketter DA, Cookman G, Gerberick GF, Hamaide N, Potokar M. Skin sensitization thresholds: determination in predictive models. *Food and Chemical Toxicology*. 1997;35(3):417-425. doi:10.1016/S0278-6915(97)00129-4
58. Cochrane SA, Arts JHE, Ehnes C, et al. Thresholds in chemical respiratory sensitisation. *Toxicology*. 2015;333:179-194. doi:10.1016/j.tox.2015.04.010

59. Matsuda T, Maruyama T, Iizuka H, et al. Phthalate esters reveal skin-sensitizing activity of phenethyl isothiocyanate in mice. *Food and Chemical Toxicology*. 2010;48(6):1704-1708. doi:10.1016/j.fct.2010.03.049
60. Maestre-Batlle D, Huff RD, Schwartz C, et al. Dibutyl Phthalate Augments Allergen-induced Lung Function Decline and Alters Human Airway Immunology. A Randomized Crossover Study. *Am J Respir Crit Care Med*. 2020;202(5):672-680. doi:10.1164/rccm.201911-2153OC
61. Uter W, Yazar K, Kratz E-M, Mildau G, Lidén C. Coupled exposure to ingredients of cosmetic products: I. Fragrances. *Contact Dermatitis*. 2013;69(6):335-341. doi:10.1111/cod.12125
62. Kartono F, Maibach HI. Irritants in combination with a synergistic or additive effect on the skin response: an overview of tandem irritation studies. *Contact Dermatitis*. 2006;54(6):303-312. doi:10.1111/j.0105-1873.2006.00792.x
63. Ma GX, Wei Z, Husni R, et al. Characterizing Occupational Health Risks and Chemical Exposures Among Asian Nail Salon Workers on the East Coast of the United States. *Journal of Community Health*. 2019;44(6):1168-1179. doi:10.1007/s10900-019-00702-0
64. McMichael AJ. Carcinogenicity of benzene, toluene and xylene: epidemiological and experimental evidence. *IARC Sci Publ*. 1988;(85):3-18.
65. Teik-Jin Goon A, Bruze M, Zimerson E, Goh C-L, Isaksson M. Contact allergy to acrylates/methacrylates in the acrylate and nail acrylics series in southern Sweden: simultaneous positive patch test reaction patterns and possible screening allergens. *Contact Dermatitis*. 2007;57(1):21-27. doi:10.1111/j.1600-0536.2007.01151.x
66. Cavelier C, Jelen G, Hervé-Bazin B, Foussereau J. [Irritation and allergy to acrylates and methacrylates. - Part I: Common monoacrylates and monomethacrylates (author's transl)]. *Ann Dermatol Venereol*. 1981;108(6-7):549-556.
67. Bowen SE. Two serious and challenging medical complications associated with volatile substance misuse: sudden sniffing death and fetal solvent syndrome. *Subst Use Misuse*. 2011;46 Suppl 1:68-72. doi:10.3109/10826084.2011.580220
68. Quach T, Von Behren J, Nelson DO, et al. Evaluating an owner-to-worker training intervention in California nail salons using personal air monitoring. *Am J Ind Med*. 2018;61(10):831-841. doi:10.1002/ajim.22897
69. Quach T, Von Behren J, Tsoh J, et al. Improving the knowledge and behavior of workplace chemical exposures in Vietnamese–American nail salon workers: a randomized controlled trial. *Int Arch Occup Environ Health*. 2018;91(8):1041-1050. doi:10.1007/s00420-018-1343-2
70. Vinson R, Volkwein J, McWilliams L. Determining the spatial variability of personal sampler inlet locations. *J Occup Environ Hyg*. 2007;4(9):708-714. doi:10.1080/15459620701540618
71. Bornstein MH, Jager J, Putnick DL. Sampling in Developmental Science: Situations, Shortcomings, Solutions, and Standards. *Dev Rev*. 2013;33(4):357-370. doi:10.1016/j.dr.2013.08.003
72. Kang M, Ragan BG, Park J-H. Issues in Outcomes Research: An Overview of Randomization Techniques for Clinical Trials. *J Athl Train*. 2008;43(2):215-221. Accessed January 24, 2021. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2267325/
73. Jordan S, Watkins A, Storey M, et al. Volunteer bias in recruitment, retention, and blood sample donation in a randomised controlled trial involving mothers and their children at six

months and two years: a longitudinal analysis. *PLoS One*. 2013;8(7):e67912. doi:10.1371/journal.pone.0067912

2.7 Appendix- Abbreviations used in Chapter 2.

1. NYS- New York State
2. NYC- New York City
3. VOCs- Volatile Organic Compounds
4. IMC- International Mechanical Code
5. GEV- General Exhaust Ventilation
6. LEV- Local Exhaust Ventilation
7. TVOC- Total Volatile Organic Compounds
8. CO_2- Carbon Dioxide
9. IAQ- Indoor Air Quality
10. ND- Not Detected
11. LOD- Limit of Detection
12. PID- Photoionization Detector
13. MMA- Methyl Methacrylate
14. ANSI/ASHRAE- American National Standards Institute /American Society of Heating, Refrigerating and Air Conditioning Engineers
15. TWA- Time- weighted average
16. OEL- Occupational Exposure Limit
17. TLV- Threshold Limit Value
18. PEL- Permissible Exposure Limit
19. REL- Recommended Exposure Limit
20. STEL- Short-Term Exposure Limit

Chapter 3 Occupational Exposure and Ventilation Assessment in New York City Nail Salons

3.1 Introduction

No longer a niche industry in the United States, revenue from nail salons has surpassed $8 billion, and the employment rate is expected to increase by over 13% in the next decade.[1] The industry is dominated by mostly small owner-operated salons, and 90% of nail salons have fewer than ten employees. In New York City (NYC), there are approximately 2000 nail salons-[2] the majority owned by Korean and Chinese immigrants. The NYC metropolitan area has the highest concentration of nail salon employment in the US.[3]According to US Census data, more than 79% of all nail salon workers are foreign-born, 96% are female, and 46% do not speak English or lack English proficiency.[4] Over the past two decades, investigators have documented occupational exposures and health effects among nail salon technicians.[5–12] Salon workers are exposed to a variety of volatile organic compounds (VOCs) including toluene, acetates, alcohols, acetone, and acrylates (see Table 3-1).[5–8,13]

In May 2015, the New York Times published three investigative reports on New York-based nail salon workers' experiences with health effects and environmental conditions in salons, along with reports of harassment, wage theft, labor violations, worker exploitation, and lack of investigation and intervention from the Labor Department.[14,15] In July 2015, the Governor of New York announced that nail salons throughout New York State (NYS) would have to comply with new ventilation regulations to protect employees and clients from exposure to chemicals used in the salons.[16,17] All salons licensed before October 2016 have five years to meet compliance, while those licensed after must have the ventilation requirements upon the establishment of the business.[17] The new ventilation requirements incorporate the 2015 International Mechanical Code (2015 IMC), which specifies general exhaust ventilation (GEV) and local exhaust ventilation (LEV) standards for nail salons and hair salons that provide nail services.[18] The GEV requirement within the 2015 IMC (Table 403.3.1.1) is a function of occupant density and area of the salon with a minimum of 20 cfm of outdoor air per person, plus an additional 0.12 cfm per ft^2 over 1000 ft^2. When the occupant density is unknown, a default value of 25 occupants per 1000ft^2 is assumed with 25 cfm/person required. The formula yields an airflow rate of 620cfm[1] for the GEV based on default values.[18,19] The LEV requirements are for source capture placed within 12 inches of manicure and pedicure task areas. The LEV is required to exhaust air directly outside at a rate no less than 50cfm per nail station.[18] No recirculation of salon air is permitted under the new policy.

In a previous study conducted by the authors of this paper, total volatile organic compounds (TVOC) and carbon dioxide (CO_2) measurements were collected to evaluate compliance with NYS regulations and establish baseline indoor air quality (IAQ) measurements.[8] The results of the previous study found that TVOC concentrations were almost ten times higher when CO_2 concentrations did not meet the GEV requirements. While this study was the first conducted in NYS to assess salon compliance, it suffered from several limitations, including IAQ measurements collected during only one weekday in each salon, and chemical-specific air sampling was not conducted.

[1] Ventilation requirements based on 2015 IMC = (20 cfm/person x 25 people) + (0.12 cfm/ft2 x 1000 Sq. Ft.) = 620 cfm

Table 3-1 Exposure ranges and correction factors for common compounds found in nail salon products.

Chemical compounds	Exposure ranges (ppm)	Detected by PID[a]	Correction Factor[23]	Publications
Toluene	0.01–0.06, 0.02–1.0*	Yes	0.5	Quach et al., 2011[6]
	0.04 – 0.16			Garcia et al.., 2015[24]
	0.014 – 0.31			Alaves et al.., 2013[11]
	0.02–0.31			Gjølstad et al.., 2006[9]
Ethyl acetate	0.02–0.15, 0.02–5.50*	Yes	4.6	Quach et al., 2011
	0.05 - 2.00			Alaves et al.., 2013
	0.01–1.19			Gjølstad et al.., 2006
Butyl acetate	0.01–0.06	Yes	2.6	Quach et al., 2011
	0.001–0.42			Gjølstad et al.., 2006
Methyl methacrylate	0.12–1.30	Yes	1.5	Quach et al.., 2011
	0.02 – 6.8			Garcia et al.., 2015
	ND- 4.1			Alaves et al.., 2013
	0.02–0.08			Gjølstad et al., 2006
Ethyl methyacrylate	0.09–3.22	No	-	Gjølstad et al., 2006
Isopropyl alcohol	0.06–2.0	Yes	6.4	Quach et al., 2011
	0.26 – 1.30			Alaves et al., 2013
Acetone	0.31–6.60	Yes	1.1	Quach et al., 2011
	1.6 - 13			Alaves et al., 2013
	0.05–16.4			Gjølstad et al., 2006
TVOCs	0.035-71	Yes	-	Pavilonis et al., 2018[8]
	0.061-38			Goldin et al.., 2014[25]
	0.33 – 4.00			Garcia et al.., 2015

***-personal air monitoring, a=RAE model # 3000 calibrated with isobutylene with a 10.6 eV lamp**

The current study aims to expand on the previous study and address the prior limitations by examining the temporal variability of key air pollutants generated in nail salons in NYC, across three days, and to determine if ventilation systems meet established standards in advance of the widespread implementation of the new requirements. This study intends to further establish CO_2

as a reliable indicator for indoor ventilation since there are no existing state-regulated protocols for doing so. Establishing baseline metrics for indoor air quality in nail salons can facilitate evaluation of progress toward public health goals of eliminating harmful exposures to salon personnel and their customers.

3.2 Methods

3.2.1 Recruitment

We approached managers of nail salons in three boroughs within NYC (Queens, Manhattan, and Brooklyn) and presented them with flyers with details of the study, including the walk-through survey and contaminant sampling protocol. Salon managers were also informed that they would be presented with a copy of an air quality report after the research was completed. Areas within NYC with a high density of nail salons were identified each recruitment day using GOOGLE Maps, and a recruiter visited salons within that area. A total of 307 salons were approached to participate in the study. Twelve salons refused to participate, 30 salons did not have a manager present, five salons had managers that did not speak English (a participation requirement), and at 248 salons participation materials were left with the manager, but the salon did not contact the investigators. Four salons agreed to participate following the authors' 2017 study, and eight new salons consented to participate in the current study. Seven of the participating salons were located in Manhattan, and five were in Brooklyn.

3.2.2 Walk-through survey

The survey began with a short questionnaire administered to the manager regarding the characteristics of the nail salon. The survey assessed the type of ventilation system in use, whether the air was exhausted directly outside or recirculated, number and type of services typically provided, and type of personal protective equipment used by salon workers (survey available upon request). We then sketched the layout of the nail salon, including the location of diffusers, intakes, and any LEV ducts, as well as the approximate location of manicure and pedicure stations, waiting area, and other rooms in the salon (massage, waxing, and other activities). Salon dimensions were determined using a laser distance measurer (GLM 30, Bosch, Gerlingen, Germany) with a maximum distance of 100 ft. Due to the ceiling configuration and location of the air-handling units, we were unable to measure exhaust rates directly. Consequently, we used average daily CO_2 concentrations to estimate outdoor airflow.

3.2.3 Air Sampling

In each salon, we deployed a device to measure CO_2, temperature, and relative humidity (IAQ-Calc model #7545, TSI Shoreview, MN) and a photoionization detector (PID), calibrated with isobutylene, with a 10.6 eV lamp (RAE model # 3000, Honeywell, Morris Plains, NJ) to measure total volatile organic compounds (TVOC) concentrations. The PID has a range of 0.05–10,000 ppm. Table 3.1 shows chemicals that have been previously identified in nail salons, whether a PID is capable of detecting them and the correction factor for the PID. The majority of common VOCs found in nail salons such as acetone, ethyl acetate, isopropyl alcohol, MMA, and toluene are detectable with a PID. For some chemicals found in nail salons, the ionizing potential is unknown; therefore, we could not assess whether it was detectable with a PID.

Radiello 130 samplers (*Millipore-Sigma*, St. Louis, MO) were used to measure daily concentrations of ethyl-acetate, toluene, and MMA. A coordinator instructed salon owners on how to open and insert the adsorbing cartridge into the diffusive body. Additionally, salon owners were asked to record daily the total exposure time of the passive monitor, the number of manicures, pedicures, and artificial nails performed, whether the ventilation system was turned on for the day, and if windows and doors were kept open. Early in the project two salons were unable to comply with the passive monitoring protocol (Salon 3 and 4). After failure between those two salons, the protocol was updated, and a coordinator sent out multiple daily reminders (morning and afternoon) via text message to remind salon managers to change out the cartridges and complete the sampling log forms. After we updated the protocol, all salons were able to adhere to the methodology for the remainder of the study.

In the prior study conducted by the authors, it was determined airborne concentrations in salons showed little spatial variability, indicating that salon air was well-mixed, and area exposure was similar throughout the salon regardless of the task being performed.[8] For this study, direct reading and passive monitors were co-located in one central location within the salon for the duration of the assessment. This allowed for evaluation of day-to-day variability in ventilation and IAQ within the salon. All direct reading instruments were calibrated according to the manufacturer's instructions and programmed to datalog concentrations every minute.

Data collection occurred from July 2018 to September 2018. Measurements were collected in each salon over a period of three consecutive days (Thursday, Friday, and Saturday). We selected these days to capture IAQ and ventilation measurements during high customer volume days. Instrumentation was set up on the Wednesday or Thursday morning, depending on the manager's schedule, when the salon was not busy and allowed to continually datalog until the salon closed. Closing time for salons in the study ranged from 7PM to 10PM. Equipment and sampling sheets were retrieved by technicians, and data were downloaded from the instruments, and passive monitors were stored according to manufacturer's instructions. Daily sampling time differed among salons and ranged from 310-689 minutes.

3.2.4 Laboratory analysis

Laboratory analyses of the Radiello 130 samplers were conducted at an American Industrial Hygiene Accredited (AIHA) Laboratory (EMSL Analytical, Inc. Cinnaminson, NJ). Gas chromatography with a Flame Ionization Detector (FID) was used to detect all analytes. The average concentration over the sampling time period was calculated from the mass of analyte found on the cartridge and the exposure time without introducing a corrective factor. The laboratory reporting limits for the contaminants quantified in the study were 9.4µg for MMA, 8.7µg for toluene, and 8.9µg for ethyl acetate. Airborne concentrations were calculated using Equation 1. Since airborne concentration is a function of exposure time, each sampling period in the study had a unique limit of detection.

Equation 1: $C=(m/Qt)(10^6)$

Where: C= airborne concentration ($\mu g/m^3$)

m= mass of contaminant (µg)

Q=chemical specific uptake rate (ml/min)

3.2.5 Estimated Outdoor Airflow Rate per Person

Outdoor airflow rates per person were calculated from equation C-1 ANSI/ASHRAE standard 62.1 and shown as Equation 2.

Equation 2: $V_O=N/(C_S-C_O)$

Where: V_O= outdoor airflow rate per person (cfm)

N = CO_2 generation rate per person (0.011 cfm)

C_S = CO_2 concentration in the space (ppm)

C_O = CO_2 concentration in outdoor air (410 ppm)

3.2.6 Statistical Analysis

SAS Statistical software (version 9.4, SAS Institute, NC) was used to conduct all statistical analyses. The data were tested for normality using the Univariate procedure that produced a statistic for skewness and normal probability plot. The data from the passive badges and the PIDs showed general skewness, even after being log-transformed; therefore, non-parametric statistical analyses were performed. Descriptive statistics, including arithmetic, means, standard deviations, and medians were calculated. Spearman Rank Order correlations were calculated for certain variables. Kruskal Wallis H Tests were used to assess differences in CO_2 and TVOC concentrations between days. Imputation for data values below the limit of detection (LOD) was performed for the results of the passive monitors and PID. The LOD was divided by the square root of 2 to derive replacement values for censored data.[20] Salon 4 did not record the number of daily nail services provided. Therefore, the median number services were imputed for the missing values.

3.3 Results

3.3.1 Salon characteristics

Descriptive data of the 12 participating nail salons are presented in Table 3-2. There was considerable variation in the volume of the salons (3020 to 15100 ft^2) and in the number of nail tables and pedicure stations ranging from 2 to 10 and 1 to 10, respectively. Although the largest salon had five times greater volume compared to the smallest, it performed fewer average daily nail services (39 to 62), suggesting physical size is a poor predictor of customer volume. Salons differed in the type of services provided, only six salons in the study performed artificial nail services, and one salon primarily specialized in spa services and had only three nail stations within the salon. Across all salons, daily average customer volume was reasonably uniform with Friday having the highest average number of services provided, and Thursday and Saturday slightly less. The majority of salon owners/managers (58%) did not have or operate their ventilation systems according to NYS regulations that specify GEV must be operated continuously while the salon is open. Of the salons that had a ventilation system installed only five managers indicated salon air was exhausted directly outside, and no salons surveyed had LEV ventilation installed.

__Table 3-2 Nail Salon Characteristics__

Characteristics	Mean (range)
Location of Salon (No.)	
Brooklyn	5
Manhattan	7
Volume (ft^3)	8100 (3020-15100)
No. of Nail Tables	6 (2-10)
No. of Pedicure Stations	6 (1-10)
Exhaust Use (No.)	
All day	5
None	2
Periodic	4
Unsure	1
Ventilation Ducted outside (No.)	
Yes	5
Recirculate	1
Unsure	4
Manicures*	
Thursday	23 (6-41)
Friday	30 (5-57)
Saturday	26 (7-66)
Pedicures*	
Thursday	21 (4-45)
Friday	26 (6-51)
Saturday	23 (6-36)
Artificial nail services**	
Thursday	5 (2-10)
Friday	6 (2-10)
Saturday	6 (2-12)
Notes: *= does not include salon 4	
****=only 6 salons performed this service**	

3.3.2 Salon indoor air quality

The results of IAQ measurements are shown in Table 3.3. Indoor summer temperatures across all salons ranged from 65.9 to 84.5°F, with an average of 77.2°F and an average humidity level of approximately 60%. Fridays had the highest average concentrations of TVOCs (37 ppm) and CO_2 (1350 ppm); however, the day of the week was not a significant predictor of TVOC or CO_2 concentrations within salons (p=*0.8155* with TVOC and p= *0.7722* with CO_2) when analyzed with a Kruskal Wallis test. Toluene, MMA, and ethyl acetate samples (N=30) were categorized as being above or below the limit of detection (LOD). Five toluene samples (mean=0.018ppm) were above the limit of detection, and 6 MMA samples (mean=0.08ppm) were above the LOD and was only detected in salons which performed artificial nail services. Ethyl acetate was observed to be most frequently above the LOD, with 27 samples being above the LOD with an average concentration of 0.67ppm.

<u>Table 3-3 Indoor Air Quality Characteristics Within All Nail Salons (n=12)</u>

Variable	Mean	Std. Dev (Range)
Temperature (°F)	77.2	3.0 (65.9-84.5)
Humidity (%)	59.4	8.3 (39.5-80.1)
TVOCs (ppm)	32	27 (0.03-426)
Thursday	31	49 (0.03-426)
Friday	37	40 (0.04-151)
Saturday	30	33 (0.04-124)
Carbon Dioxide (ppm)	1261	577 (125-3530)
Thursday	1183	536 (426-2574)
Friday	1350	746 (437-3530)
Saturday	1250	583 (125-2460)
Toluene (ppm)*	0.018	0.035 (0.031-0.180)
No. above LOD	5	
No. below LOD	25	
Methyl Methacrylate (ppm)*	0.08	0.239 (0.035-1.30)
No. above LOD	6	
No. below LOD	24	
Ethyl Acetate (ppm)*	0.67	0.686 (0.033-2.810)
No. above LOD	27	
No. below LOD	3	
Notes: *= Excludes Salons 3 & 4 due to lack of compliance with the sampling protocol		

A Spearman rank-order correlation was calculated to determine the correlation between salon variables and average daily TVOC concentrations with the most relevant correlations presented in Table 3-4. The number of daily services or salon density (total number of daily services divided by salon volume) was not significantly correlated with TVOC concentrations. There was a statistically significant negative correlation between mean TVOCs and estimated outdoor airflow rate per person ($p<0.01$). A negative association was observed between larger salon volume and higher TVOC ($p=0.07$).

<u>Table 3-4 Spearman Rank Order Correlations between select variables and Average TVOC concentrations</u>

Variables	*r*	*p-value*
Daily services	-0.10	0.58
Salon Volume	-0.31	0.07
Salon Density	0.16	0.36
Estimated Outdoor Airflow Rate per Person	-0.69	*<0.01*

3.3.3 Ventilation in nail salons

The average outdoor airflow rate per person (cfm) over the three sampling days was calculated for all salons (Table 3-5). Only three salons (1, 8, and 9) were compliant with the GEV requirements of 25 cfm of outdoor airflow, air exhausted directly outdoors, and exhaust used all day. These three salons also had no detectable amounts of MMA or toluene and had roughly half the concentrations of TVOC (16 ppm to 33 ppm) compared to salons that did not meet the requirements. Additionally, compliant salons had double the number of average services performed compared to salons that were not 83 to 42, respectively. Two salons also met the minimum guidelines of outdoor airflow (32 cfm and 322 cfm), but the primary source of ventilation was from open windows and did not have a dedicated exhaust installed. One of these two salons had detectable levels of MMA, and the other had detectable levels of toluene. Of the five salon managers that indicated they were unsure if salon air was recirculated, all failed to meet the 25 cfm of outdoor air.

3.4 Discussion

3.4.1 Air quality in nail salons

The objectives of this study were to understand day-to-day variability in contaminant concentrations and evaluate existing GEV rates in nail salons located in NYC. Although the NYS regulations deadline of October 2021 is rapidly approaching, salons surveyed in this study appear unprepared to comply with the requirements. To date, there have been no updates regarding a delay in deadline for compliance due to the COVID-19 pandemic. None of the salons installed LEV systems, and only 25% of the salons met the GEV requirements. Two of the salons that did meet the minimum outdoor airflow rate had no exhaust system and utilized open windows for ventilation. This may be practical during the summer months (when sampling was done) but is impractical during the colder seasons when windows will remain closed. Salons should calculate the amount of outdoor air required based on maximum salon occupancy to ensure proper exhaust rates per person and to achieve the most considerable reduction in contaminant concentrations. Additionally, none of the participating salons had local exhaust ventilation, which would improve indoor air quality by capturing contaminants released near workers and customers during nail services.

Table 3-5. Ventilation and salon characteristics

ID	Mean Services	Salon Volume (ft^3)	TVOC (ppm)	Outdoor Airflow (cfm)	Exhaust Use	Ducted outside	Windows Open
1	106	8034	17.4	25.8	All day	Yes	No
2	45	3831	70.5	12.8	Unsure	Yes	No
3	10	5082	28.3	7.3	Periodic	unsure	Yes
4	50	5416	44.3	13.5	Periodic	Unsure	No
5	20	5492	6.6	16.0	All day	Unsure	No
6	39	15100	67.4	14.5	All day	Unsure	No
7	62	3021	22.4	32.0	None	None	Yes
8	71	14092	2.1	57.6	Periodic	Yes	No
9	79	9974	27.7	28.2	All day	Yes	No
10	50	7386	49.1	14.0	Periodic	Yes	No
11	52	9684	9.5	20.6	All day	recirculate	No
12	46	10205	1.3	322.2	None	None	Yes

Despite new regulations implemented by the state, results from this study indicate salon managers still have limited knowledge regarding the operation of their ventilation systems. Numerous managers were unaware if indoor air was exhausted directly outside or recirculated within the salon. Recirculated air is not permitted according to the NYS ventilation requirements, and salons must have a dedicated exhaust that is in operation throughout the day. Additionally, some managers indicated that the exhaust system was used only periodically throughout the day or they were unsure about the use of the exhaust system at all. This shows the need for specific health and safety training among salon workers regarding the operation and maintenance of the ventilation system. Data from this study can be used as evidence of reduction in exposure due to compliance with the GEV requirements. Salons that met the GEV requirements had twice the customer volume and half the TVOC concentrations as salons that did not. The findings of this study were generally similar to a few other studies conducted in the metropolitan areas of New York and Massachusetts. Public health officials should target smaller customer volume salons for health and safety training given the lack of knowledge of the systems by managers observed in this study.

3.4.2 Carbon dioxide: an indicator of indoor air quality of nail salons

One of the challenges with the new regulation is determining compliance. NYC has approximately 2000 nail salons, and ventilation measurements need to be performed quickly and efficiently without the interruption of business. Ventilation assessments may be especially problematic in salons located in high-rise buildings if the salon owner does not have direct access to the system. This study demonstrates CO_2 can be used an efficient indicator of ventilation performance in the absence of direct ventilation measurements. Day of the week was not significantly associated with ventilation and exposure measurements, and representative measurements can be performed on high customer volume days for purposes of determining compliance.

Chemical-specific air sampling showed a substantial number of non-detects for toluene and MMA while, ethyl acetate was readily detected in salons. This is consistent with previous exposure studies that found similar airborne concentrations of the three chemicals in nail salons.[6–12] Given the high TVOC concentrations relative to the chemicals specifically quantified, the majority of exposures to nail salon workers are likely from alcohols and acetone, which were not quantified individually and are underestimated by the PID. In this study, the only salon with detectable toluene readings across the three days provided a variety of spa services and was not primarily a nail salon. The absence of toluene in nail salons may be due to the movement away from using "the toxic trio" of chemicals in nail products: toluene, formaldehyde, and dibutyl phthalate (DBP).[21] Ethyl acetate was detected frequently in the salons (90%), albeit at concentrations well below the TLV, with concentrations ranging from 0.09-1.68ppm and comparable to previous exposure assessments conducted in nail salons (0.01-5.5ppm).[6,9] MMA was only in salons that performed artificial nail services. As discussed above, monomeric MMA use is prohibited in New York.[22] MMA may continue to be used as a component of acrylic nail preparations, or it may be a contaminant or by-product of other acrylates. The levels of MMA detected in this study (0.12-1.30ppm) are comparable to a Norwegian nail salon study and another study conducted in California.[6,9]

Compared to the 2017 study[8] conducted by the authors, salons included in this study were smaller (8100 ft^3 vs. 14200 ft^3) with a higher number of salons located outside of Manhattan. While both studies demonstrated an increase in outdoor airflow was effective in reducing TVOC concentrations, this study specifically addressed compliance with the NYS regulation, which stipulates salons must have dedicated exhaust directed outside and cannot rely on natural ventilation to achieve compliance. We also updated our sampling protocol to collect information regarding the number of nail services performed daily. Additionally, this current study evaluated daily within salon variability over a three-day period and included analyses of key VOCs found in nail salons. The results showed that there was no significant within salon variability over the three-day period and concentrations of individual chemicals.

This study, like previous exposure assessments conducted in nail salons, was limited by relying on a convenience sample of a few salons. We visited over 300 nail salons for this study, but only twelve agreed to participate. We hypothesized that salons that were more willing to participate in the study were more concerned or knowledgeable about the ventilation and the current air quality within their salons. Non-participating salons were generally more wary of the research we wanted to conduct and perhaps found it too invasive These salons shared many similar features with regards to design, service types and products, and business hours. Despite a relatively small sample size, one of the strengths of this study is that the findings can be generalized because the salons that participated are representative of other salons in the general NYC region. Another strength of this study is the use of multi-day sampling to investigate temporal variability in air quality in nail salons, which has not been done before. This study further validates CO_2 as a reliable indicator of indoor air quality. Additionally, the results of this paper can be used to inform specific training programs for salon staff when the ventilation systems are installed.

3.5 Conclusion

This study further demonstrates the effectiveness of general exhaust ventilation to reduce occupants' exposure to VOC. Contrary to our initial hypothesis, the number of nail services was not associated with increased TVOC concentrations, and higher customer volume salons were more likely to be in compliance with the regulations. Many of the salon managers were unable to answer questions regarding the use and operation of their ventilation system. It is expected that many other salons, sharing similar characteristics to the ones in this study, may not be in compliance with the ventilation regulations. More outreach to nail salons is needed by the state in preparation for the new requirements going into effect in October 2021.

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3.6 References

1. US Department of Labor, Bureau of Labor Statistics. *Occupational Outlook Handbook: Manicurist and Pedicurists Job Outlook*.; 2016. https://www.bls.gov/ooh/personal-care-and-service /manicurists-and-pedicurists.htm.
2. Federman MN, Harrington DE, Krynski KJ. The Impact of State Licensing Regulations on Low-Skilled Immigrants: The Case of Vietnamese Manicurists. *The American Economic Review*. 2006;96(2):237-241.
3. US Department of Labor, Division of Occupational Employment Statistics. *Occupational Employment and Wages, May 2018: 39-5092 Manicurists and Pedicurists*.; 2019. https://www.bls.gov/oes/current/oes395092.htm#(1).
4. US Census Bureau. *2012–2016 American Community Survey 5-Year Sample*.; 2016.
5. Roelofs C, Azaroff LS, Holcroft C, Nguyen H, Doan T. Results from a Community-based Occupational Health Survey of Vietnamese-American Nail Salon Workers. *J Immigrant Minority Health*. 2008;10(4):353-361. doi:10.1007/s10903-007-9084-4
6. Quach T, Gunier R, Tran A, et al. Characterizing Workplace Exposures in Vietnamese Women Working in California Nail Salons. *American Journal of Public Health*. 2011;101(S1):S271-S276. doi:10.2105/ajph.2010.300099
7. Ma GX, Wei Z, Husni R, et al. Characterizing Occupational Health Risks and Chemical Exposures Among Asian Nail Salon Workers on the East Coast of the United States. *J Community Health*. July 2019. doi:10.1007/s10900-019-00702-0
8. Pavilonis B, Roelofs C, Blair C. Assessing indoor air quality in New York City nail salons. *Journal of Occupational and Environmental Hygiene*. 2018;15(5):422-429. doi:10.1080/15459624.2018.1447117
9. Gjølstad M, Thorud S, Molander P. Occupational exposure to airborne solvents during nail sculpturing. *Journal of Environmental Monitoring*. 2006;8(5):537-542. doi:10.1039/B601917J
10. Arrandale V, Kalenge S, Nguyen LV, Kirkham T, Diamond ML, Holness DL. Occupational Exposures among Nail Technicians in Toronto, Canada. *ISEE Conference Abstracts*. September 2018. http://ehp.niehs.nih.gov/doi/10.1289/isesisee.2018.S03.04.39. Accessed July 10, 2019.
11. Alaves VM, Sleeth DK, Thiese MS, Larson RR. Characterization of indoor air contaminants in a randomly selected set of commercial nail salons in Salt Lake County, Utah, USA. *International Journal of Environmental Health Research*. 2013;23(5):419-433. doi:10.1080/09603123.2012.755152
12. Park S-A, Gwak S, Choi S. Assessment of Occupational Symptoms and Chemical Exposures for Nail Salon Technicians in Daegu City, Korea. *J Prev Med Public Health*. 2014;47(3):169-176. doi:10.3961/jpmph.2014.47.3.169
13. Roelofs C, Do T. Exposure Assessment in Nail Salons: An Indoor Air Approach. *ISRN Public Health*. 2012;2012:1-7. doi:10.5402/2012/962014

14. Nir SM. The Price of Nice Nails. *The New York Times*. https://www.nytimes.com/2015/05/10/nyregion/at-nail-salons-in-nyc-manicurists-are-underpaid-and-unprotected.html. Published May 8, 2015. Accessed June 12, 2019.
15. Nir SM. Perfect Nails, Poisoned Workers. *The New York Times*. https://www.nytimes.com/2015/05/11/nyregion/nail-salon-workers-in-nyc-face-hazardous-chemicals.html. Published May 13, 2015. Accessed June 12, 2019.
16. International Code Council, Inc. *Section 160.16 of Part 160 of Title 19 of the New York Codes, Rules and Regulations*. Washington,DC; 2016. https://www.dos.ny.gov/licensing/appearance/ventingreg.html.
17. Office of the Govenor, New York State. Governor Cuomo Announces New Ventilation Standards For Nail Salons. Governor Andrew M. Cuomo. https://www.governor.ny.gov/news/governor-cuomo-announces-new-ventilation-standards-nail-salons. Published July 22, 2016. Accessed June 18, 2019.
18. NYS Department of State. *Ventilation Requirements For Nail Specialty Services Guidance Document For Contractors And Design Professionals*.; 2016. https://www.dos.ny.gov/licensing/appearance/NailSalon%20Technical%20document.%20final.pdf.
19. International Code Council, Inc. Chapter 4 Ventilation | 2015 International Mechanical Code. November 2015. https://codes.iccsafe.org/content/IMC2015/chapter-4-ventilation?site_type=public. Accessed June 24, 2019.
20. Succop PA, Clark S, Chen M, Galke W. Imputation of data values that are less than a detection limit. *J Occup Environ Hyg*. 2004;1(7):436-441. doi:10.1080/15459620490462797
21. Breskey JD. California Again Leading the Way: Cosmetics Safety and Worker Health. *Californian Journal of Health Promotion*. 2013;11(1):vi-viii.
22. CDC NIOSH. Epoxies and Resins - NIOSH Workplace Safety and Health Topic. https://www.cdc.gov/niosh/topics/repro/epoxiesresins.html. Published November 20, 2018. Accessed July 10, 2019.
23. Hsi P, Nègre T, Sheikhan B. *The PID Handbook: Theory and Applications of Direct-Reading Photoionization Detectors*. 3rd ed. San Jose, CA: RAE Systems Inc.; 2013.
24. Garcia E, Sharma S, Pierce M, et al. Evaluating a county-based healthy nail salon recognition program. *American Journal of Industrial Medicine*. 2015;58(2):193-202. doi:10.1002/ajim.22379
25. Goldin LJ, Ansher L, Berlin A, et al. Indoor Air Quality Survey of Nail Salons in Boston. *Journal of Immigrant and Minority Health*. 2013;16(3):508-514. doi:10.1007/s10903-013-9856-y

Chapter 4 : An estimation of the airborne SARS-CoV-2 infection transmission risk in nail salons in New York City

4.1 Introduction

Amid the ongoing COVID-19 pandemic, an understanding of the potential route(s) of transmission of SARS-CoV-2, the virus responsible for causing COVID-19, is critical in designing and implementing effective infection control measures. During the early stages of viral spread in the United States, infection mitigation strategies focused on viral transmission via fomites or inanimate objects and surfaces that may carry infectious agents, such as door handles and elevator buttons. Exponential decay of SARS-CoV-2 has been observed across different media, with half-lives ranging from 5.6 hours on stainless steel to 6.8 hours on plastic.[1] Large (>5-10 µm), virus-containing respiratory droplets emitted when an infected individual coughs, sneezes, or talks, for instance, may contaminate a surface[2]. Self-inoculation with SARS-CoV-2 could, therefore, occur if a susceptible (i.e., non-COVID-19-infected) individual touches the contaminated surface and subsequently touches the mucous membranes of their nose, mouth, or eyes.[2,3] As such, initial recommendations consisted primarily of frequent handwashing and disinfection of high-touch surfaces with U.S. Environmental Protection Agency (EPA)-registered disinfectants[4].

At the time of publication, however, the state-of-the-science as reported by the U.S. Centers for Disease Control and Prevention (CDC) suggests that while adequate hygiene and disinfection are important, indirect transmission via fomites "is not thought to be the main way the virus spreads".[5] Rather, a growing body of epidemiological evidence indicates that this novel human coronavirus is primarily spread from person-to-person via respiratory droplets or droplet nuclei.

This means that the risk of airborne SARS-CoV-2 infection transmission is likely highly dependent on both the duration of exposure and proximity to an infectious individual. Infectious respiratory droplets may land on a susceptible individual's mucous membranes in close contact with an infected individual or may be inhaled by a susceptible individual nearby.[5]. The CDC has defined 'close contact' as being "within 6 feet of an infected person for at least 15 minutes starting from 2 days before illness onset (or, for asymptomatic patients, two days before positive specimen collection) until the time the patient is isolated".[6] Indeed, many COVID-19 outbreaks have originated in indoor environments, including restaurants[7], churches[8], and cruise ships[9], where individuals congregate for extended periods and are talking, shouting, or singing – all activities that tend to produce respiratory droplets. Recommendations for universal (and proper) use of face masks and social distancing among the general public have proven effective in curtailing the community spread of COVID-19.[10]

However, these control measures may not be sufficiently protective to mitigate transmission risk via droplet nuclei shed by infectious individuals. Droplet nuclei are airborne residues (generally, ≤5 µm) of infectious aerosols from which most respiratory fluid has evaporated[2]. It has been demonstrated under experimental conditions that SARS-CoV-2 in aerosolized form may remain viable for up to approximately three hours (range: 0.64-2.64 hours)[1]; real-world evidence for airborne transmission of SARS-CoV-2 is still being gathered[11,12]. Given the currently available information regarding airborne transmission of SARS-CoV-2 and related viruses, it is reasonable to assume that COVID-19 transmission may occur if a susceptible individual inhales a sufficient quantity of viable droplet nuclei. However, our understanding is that during the compilation of this paper, the infectious dose of SARS-CoV-2 above which there is a significantly increased risk of developing COVID-19, has not yet been established. Therefore, in addition to infection control measures like social distancing and face masks, attention must be given to ensuring adequate engineering controls in indoor environments (e.g., outdoor airflow), particularly in occupational settings where workers may be indoors for eight hours a day and interact with numerous individuals throughout the workday.

One example of an indoor, occupational environment where workers may experience prolonged contact with many individuals on any given day is the nail salon. Indeed, the American Industrial Hygiene Association (AIHA) has recently issued a COVID-19 guidance document specifically related to business reopening recommendations for nail salons[13]. We have investigated indoor air quality issues at various nail salons in New York City. In a pilot study of 10 salons, total volatile organic compounds (TVOC) and carbon dioxide (CO_2) concentrations were measured[14], and we found that contaminant variation was generally minimal within each salon (i.e., well-mixed room). In a subsequent study, we estimated outdoor airflow rates per person using CO_2 concentrations in 12 nail salons over three consecutive days. We found little daily variation in airflow rates within salons; however, there were orders of magnitude differences in outdoor airflow rates between salons.[15]

Sufficient outdoor airflow is a critical precautionary measure when mitigating airborne infection transmission risk. As such, nail salons represent an important occupational setting in which airborne SARS-CoV-2 infection transmission risk for both employees and customers should be evaluated. New York City has more than 2,000 nail salons that employ over 27,000 individuals [16]. On July 6, 2020, New York City entered Phase 3 of reopening, which allowed for the reopening of personal care services, including nail salons, with precautionary measures in-place[17]. As of this same date, there were approximately 216,000 cases of COVID-19 in New York City, with about 18,600 confirmed deaths and about 4,600 probable deaths due to COVID-19.[18].

While three primary modes of transmission (1. Contact via fomites, 2. Respiratory droplet transmission, and 3. Airborne [droplet nuclei] transmission) have been postulated during the COVID-19 pandemic, the focus of the current study is the risk of potential airborne transmission of SARS-CoV-2 in New York City nail salons. To estimate the risk of airborne infection transmission of SARS-CoV-2 in the confined, indoor spaces of New York City nail salons, the Wells-Riley equation can be utilized. This model was developed by Riley et al. (1978) to quantitatively assess the airborne risk of measles transmission during an outbreak in New York State in 1974. Riley et al. (1978) based their model on the 'quantum of infection' concept first introduced by William Firth Wells in 1955 to signify the smallest dose of any infectious agent to cause infection in 63% of susceptible hosts.[19] As explained by Rudnick and Milton (2003), "exposure to one quantum of infection gives an average probability of 63% ($1 - e^{-1}$) of becoming infected (essentially an infectious dose 63%, ID_{63}). The belief that multiple independently deposited organisms are required to initiate infection is not borne out by biological evidence, nor is it biologically plausible. Thus *q* represents the generation rate of infectious doses, not organisms or infectious particles; it is the average infectious source strength of infected individuals".[20] The infectious dose of SARS-CoV-2 that may ultimately lead to COVID-19 development is unknown. However, the infectious dose (LD_{10} and LD_{50}, respectively) for SARS-CoV-1 in animal studies was estimated to be 43 to 280 plaque-forming units (PFU) [21]. Using the average infectious dose coefficient (0.02) derived by Watanabe et al. (2010), the viral load of the sputum (10^9 RNA virus copies mL^{-1}), and light exercise as the level of activity, the resulting quanta generation rate for SARS-CoV-2, as reported by Buonanno et al. (2020), was 142 quanta/hr.

This study's objective was to estimate the risk of airborne SARS-CoV-2 infection transmission in New York City nail salons under steady- and non-steady-state conditions using previously estimated outdoor airflow rates.[15]

4.2 Methods

4.2.1 Estimated Outdoor Airflow Rate

We were unable to measure outdoor airflow rates directly. Therefore, we estimated outdoor airflow rates per person using Equation 6 from ASTM Standard D6245-18 and shown as Equation 1. The CO_2 generation rate was selected for a female aged 21 to < 30 years performing light work, and 410 ppm was the average measured outdoor CO_2 concentration[22]. We multiplied the outdoor airflow rate per person by the number of workers and customers assumed to be in the salon at any given time based on logs provided by the salon owner. Carbon dioxide measurements were collected in each salon over three consecutive days (Thursday, Friday, and Saturday) and averaged.

$$V_o = \left[\frac{N}{C_S - C_o}\right] \times 10^6 \qquad \text{Eq. 1}$$

Where:

V_O = Outdoor airflow rate per person (m^3/s)

N = CO_2 generation rate per person (0.0000052 m^3/s)

C_S = CO_2 average concentration in the space (ppm)

C_O = CO_2 concentration in outdoor air (410 ppm)

As noted, outdoor airflow rates per person (m^3/s-person) were previously estimated in 12 nail salons located in New York City[15]. They were used to calculate the risk of airborne SARS-CoV-2 infection transmission using the Wells-Riley equation. To calculate the total outdoor airflow rates (m3/min) in the nail salons (Table 4.1), the number of employees and customers was multiplied by the outdoor airflow rate per person.

In addition to elimination through exhausted air, airborne droplets can be removed by viral inactivation (λ) and gravitational settling (k). Viral inactivation refers to the chemical and physical changes in aerosolized viruses that result in loss of infectivity [23]. Buonanno et al. (2020) derived the value of k from a previously calculated settling velocity of particles that were approximately 1µm.[24]. The diameter of SARS-CoV-2 particles ranges from 0.06 to 0.14 µm [25]. Viral decay was adopted from van Doremalen et al. (2020) based on the SARS-CoV-2 half-life of 1.1 hours. The values of k and λ for virus removal were expressed as increased ventilation in the room, with k being 0.24 air changes/hour (ACH) and λ being 0.64 ACH. The number of ACH was multiplied by each nail salon's volume and added to the total outdoor airflow rate.

4.2.2 Impact of Face Mask Use

The risk of airborne infection transmission can further be reduced by infected and susceptible individuals wearing face masks. In most public, commercial settings in New York City, social distancing and face mask-wearing orders have been enacted (e.g., New York State's 10-Point PAUSE Plan and New York Governor's Executive Order No. 202.17). For this study's purpose, the term 'face mask' generally encompasses N95 respirators, surgical masks, and homemade fabric masks or other face coverings. However, it should be noted that the efficacy of face masks depends on the type.

Various forms of face masks have been found to reduce the transmission of respiratory viruses by 60% to 80%, and these viral transmission rates can be further reduced when face masks are worn in conjunction with adherence to social distancing protocols.[26–29]. This paper uses a conservative value of a 60% reduction in viral transmission from face mask-use by an infected individual. It expresses this transmission reduction as a 60% decrease in the quanta generation rate (q). To account for the reduction of exposure when a susceptible person is wearing a face mask, we also used the conservative value of 60% and expressed this as a 60% increase in the outdoor airflow rates (Q).

4.2.3 Steady-State Conditions

The probability of airborne infection transmission (P) in a room with a steady-state concentration is shown in Equation 2 (i.e., the Wells-Riley equation).

$$P \times 100 = 1 - e^{\left(-\frac{Iq(IR)t}{Q}\right)} \qquad \text{Eq. 2}$$

Where:

P = Probability of airborne infection transmission

I = Number of infected individuals (assumed as one [1] in this study)

q = Quanta generation rate (quanta/min)

IR = Inhalation rate (0.016 m^3/min) [30]

t = Time (min)

Q = Outdoor airflow rate (m^3/min)

To calculate the risk of airborne infection transmission under steady-state conditions, the following scenarios were used:

(1) Scenario 1: A susceptible employee is exposed to one infected employee for 480 minutes (8 hours).

(2) Scenario 2: One susceptible customer is exposed to one infected employee for 60 minutes at any given time.

4.2.4 Non-Steady-State Conditions

The traditional Wells-Riley model assumes steady-state ventilation conditions in which there is a constant generator of infectious particles.[31] However, New York City nail salons do not meet this criterion if it is assumed that the infectious particles generator is a customer who briefly visits the salon and subsequently leaves after some time. Thus, the quanta concentration (q_c) upon entrance to a nail salon by an infected individual was calculated using Equation 3.

$$q_c = \frac{q}{Q}\left[1 - e^{\left(\frac{-Qt}{V}\right)}\right] \quad \text{Eq. 3}$$

Where:

q_c = Quanta concentration (quanta/m^3)

q = Quanta generation rate (quanta/min)

Q = Outdoor airflow rate (m^3/min)

t = Time (min)

V = Volume of salon (m^3)

Equation 4 was then used to estimate the decrease in quanta concentration (decay) when an infected individual exits the nail salon at t_2.

$$q_{c2} = q_{c1} \times e^{\left[-\frac{Q}{V}(t_2 - t_1)\right]} \quad \text{Eq. 4}$$

Where:

q_{c1} = Initial quanta concentration (quanta/m^3)

q_{c2} = Quanta concentration following decay (quanta/m^3)

4.2.5 Risk of Airborne Infection Transmission under Non-Steady-State Conditions

Quanta concentration (q_c) was averaged over the scenario times and was used to calculate airborne infection transmission risk (R), as shown in Equation 5.

$$R(\%) = 100 \times \left[1 - e^{(-IPtq_c)}\right] \quad \text{Eq. 5}$$

Three hypothetical exposures scenarios were used to calculate the risk of airborne SARS-CoV-2 infection transmission among employees and customers for non-steady-state conditions:

(3) Scenario 3: One susceptible customer and one infected customer enter the nail salon together and stay for 30 minutes.

(4) Scenario 4: One infected customer enters and stays for 45 minutes, while one susceptible customer enters 30 minutes after the infected customer and stays for 60 minutes.

(5) Scenario 5: One infected customer and one susceptible customer enter simultaneously and stay for 150 minutes (2.5 hours).

4.2.6 Statistical Analysis

Pearson's correlation coefficients (*r*) were calculated to evaluate potential associations between each nail salon's outdoor airflow rate and the risk of airborne infection transmission. We assumed scenarios with and without face mask use for all five exposure scenarios together, as well as for steady-state (i.e., Scenarios 1-2) and non-steady-state (i.e., Scenarios 3-5) conditions, separately. The normality of the data was first assessed using the Shapiro-Wilk test for normality (null hypothesis [H_0] = data are normally distributed). If the p-values for the Shapiro-Wilk test were greater than 0.05 for each scenario we assessed, then H_0 was unable to be rejected, and it was assumed that the modeled data were normally distributed. The statistical analysis was performed using SAS® software (9.4, SAS Institute Inc., Cary, NC, USA).

4.3 Results

The estimated outdoor airflow rates, adjusted for airborne virus removal from gravitational settling (k) and viral decay (l), are presented in Table 4.1. The average outdoor airflow rate across all salons was 16.63 m3/min and ranged from 3.72 to 94.19 m3/min. Salon 12 had the greatest outdoor airflow rate and relied on natural ventilation and did not have a dedicated HVAC system.

Table 4-1 Nail Salon Characteristics

	Salon											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Volume (m^3)	227.5	108.5	143.9	153.4	155.5	427.6	85.5	399	282.4	209.1	274.2	289
Ventilation Rate (m^3/min)*	14.1	5.17	3.72	6.06	5.9	9.46	10.24	21.99	11.89	6.99	9.8	94.19
No. of Occupants**	15	10	8	10	8	8	10	10	12	10	10	10

*** Adjusted for gravitational settling (*k*) and viral decay (λ)**
**** Average number of customers and employees at any given time**

The risk of airborne SARS-CoV-2 infection transmission varied substantially across salons, particularly when accounting for the use of face masks. The risk of airborne infection transmission across all salons and all exposure scenarios (i.e., under both steady- and non-steady-state conditions) when not wearing face masks ranged from <0.015% to 99.25%, with an average airborne infection transmission risk of 24.77%. Additionally, wearing face masks resulted in an airborne infection transmission risk ranging from <0.01% to 51.96%, with an average airborne infection transmission risk of 7.30%.

4.3.2 Steady-State Scenarios

Compared to airborne infection transmission risk calculated for similar exposure scenarios under non-steady-state conditions, the risk values derived using the Wells-Riley airborne infection transmission risk model under steady-state conditions were generally higher. Two exposure scenarios, assuming steady-state conditions, are compared in Table 4-2. These exposure scenarios are compared, assuming neither an infected nor a susceptible individual wore face masks versus when both the infected and susceptible individuals were wearing face masks. When wearing face masks, the airborne infection transmission risk was based on the assumption that both the infected and susceptible individuals were wearing face masks, reflecting current precautionary measures to be undertaken when utilizing personal care services in New York City New York State law, as noted above.

Table 4-2 Risk of infection (%) for two exposure scenarios, based on steady-state conditions, without (N) or with (Y) a face mask

Salon	**Scenario 1**		**Scenario 2**	
	N (%)	Y (%)	N (%)	Y (%)
1	72.44	17.58	14.88	2.39
2	97.02	40.96	35.54	6.38
3	99.25	51.96	45.71	8.76
4	95.00	36.21	31.24	5.46
5	95.40	36.99	31.94	5.61
6	85.34	25.03	21.34	3.54
7	83.04	23.38	19.89	3.27
8	56.24	11.66	9.820	1.54
9	78.30	20.48	17.38	2.82
10	92.56	32.29	27.74	4.76
11	84.35	24.30	20.69	3.42
12	17.54	2.850	2.380	0.36

Across all nail salons, the risk of airborne infection transmission was greatest in Scenario 1, in which a susceptible employee spends a full workday (8 hours) with an infected employee. Wearing face masks resulted in a risk of airborne infection transmission that was generally much less than not wearing face masks for each salon. For example, the risk of airborne infection transmission in Scenario 1 ranged from 17.54% to 99.25% when neither party was wearing face masks but decreased substantially to 2.85% to 51.96% when both parties wore face masks. Overall, there was an approximately 2- to 6-fold risk reduction in Scenario 1 when face masks were worn. Furthermore, steady-state quanta concentrations were achieved between 25 to 256 minutes across all 12 salons for Scenario 1. In Figure 4.1, for example, steady state was reached in 118 minutes in Salon 1.

4.3.3 Non-Steady-State Scenarios

Table 4.3 compares airborne infection transmission risk under non-steady-state conditions for all salons when occupants (employees and customers) were not wearing face masks versus when they were.

Table 4-3 Risk of infection (%) for three non-steady-state exposure scenarios

Salon	Scenario 3		Scenario 4		Scenario 5	
	N (%)	Y (%)	N (%)	Y (%)	N (%)	Y (%)
1	4.27	1.35	0.68	0.04	7.690	1.98
2	9.71	3.25	3.26	0.26	19.58	5.31
3	8.84	3.19	9.83	1.47	25.47	7.28
4	7.43	2.53	3.83	0.37	16.91	4.54
5	7.43	2.55	4.18	0.43	17.31	4.67
6	3.17	1.14	4.42	0.73	10.71	2.91
7	7.69	2.24	0.10	0.00	10.43	2.72
8	2.59	1.04	0.70	0.23	5.000	2.03
9	4.02	0.94	1.78	0.01	9.020	1.28
10	5.79	2.01	4.17	0.48	14.75	3.95
11	4.36	1.49	2.75	0.30	10.79	2.84
12	1.06	0.28	0.00	0.00	1.190	0.30

Note: N= Not wearing a mask, Y= wearing a mask

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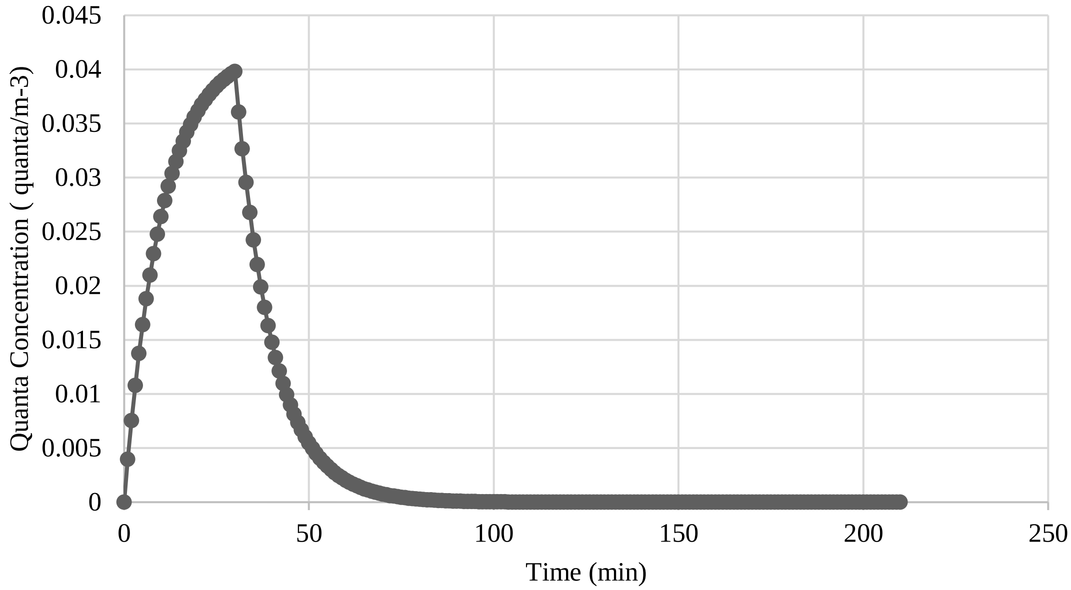

Figure 4.1 Illustration of quanta concentration decay as infected individual enters and then exits Salon 1 (Scenario 1)

As demonstrated in Figure 4.2, when the infected customer leaves the nail salon, the quanta concentration decreases and eventually reaches zero after 91 minutes, which is achieved at an outdoor airflow rate of 14.1m^3/min. Smaller nail salons with lower outdoor airflow rates typically had a higher risk of airborne infection transmission across all exposure scenarios evaluated. Salon 12, with an outdoor airflow rate of 94.19 m^3/min had a risk of airborne infection transmission ranging from <0.015% to 17.54% (mean = 2.59%) across all five scenarios, while Salon 3 with the lowest outdoor airflow rate of 3.72 m^3/min had a risk of airborne infection transmission ranging from 1.47% to 99.25% (mean = 26.17%). Steady-state concentrations were reached fastest in Salon 12 (25 min) and slowest in Salon 6 (232 min), which had the highest volume (427.6 m^3).

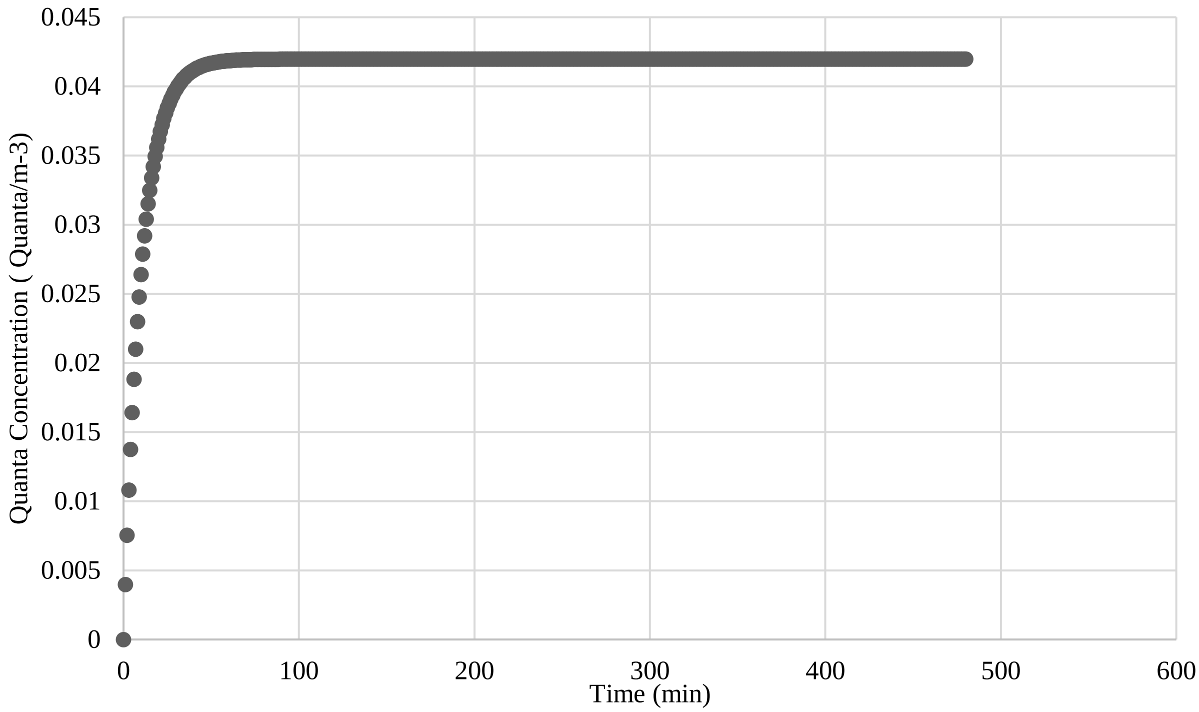

Figure 4.2. Illustration of quanta concentration increasing steadily and reaching steady-state in Scenario 4

In some exposure scenarios, the risk of airborne infection transmission was reduced substantially when wearing face masks. For example, in Salon 1 for Scenario 4, the risk of airborne infection transmission was reduced by 17-fold when a face mask was worn by both parties; however, in the same scenario for Salon 3, which had the lowest outdoor airflow rate, the risk of airborne infection transmission was reduced more than 6-fold when a face mask was worn by both parties.

4.3.4 Pearson's Correlation Coefficients

The modeled airborne infection transmission risk data were all assumed to be normally distributed since the Shapiro-Wilk p-values for each scenario we assessed were greater than 0.05. In general, the outdoor airflow rates for each nail salon were negatively and strongly associated with airborne infection transmission risk (Table 4.4). In other words, as outdoor airflow rates increased within a nail salon, the risk decreased. For example, for steady-state conditions (i.e., Scenarios 1-2) assuming no use of face masks, there was a strong, negative correlation between outdoor airflow rate and average airborne infection transmission risk (*r* = -0.878; p<0.001). Similarly, a correlation of *r* = -0.650 (p = 0.022) was calculated for non-steady-state conditions (i.e., Scenarios 3-5) assuming no use of face masks.

Table 4-4 Table 4.4. Pearson's correlation coefficients (r) for nail salon ventilation rates and infection risk

Average Infection Risk (%)	*r*	*P-value*
Scenarios 1-5; no face masks	-0.833	<.001
Scenarios 1-5; face masks	-0.681	0.014
Scenarios 3-5; no face masks	-0.650	0.022
Scenarios 3-5; face masks	-0.620	0.031
Scenarios 1-2; no face masks	-0.878	<.001
Scenarios 1-2; face masks	-0.690	0.013

4.4 Discussion

The objective of this study was to estimate the airborne infection transmission risk of SARS-CoV-2 among employees and customers in nail salons in New York City as businesses reopen in the wake of the pandemic. Previously published outdoor airflow rate data[15] and a quanta generation rate for SARS-CoV-2[30] were used in the Wells-Riley model to assess the risk of airborne infection transmission under various hypothetical exposure scenarios characterized by the interaction of employees and customers in nail salons in New York City. The modeled data indicates that adequate outdoor airflow rates and the use of face masks by both employees and customers could substantially reduce the risk of airborne SARS-CoV-2 transmission in New York City nail salons.

4.4.1 The role of ventilation in transmission risk

In New York City, many nail salons have adopted the CDC's guidelines for protecting employees and customers, such as practicing social distancing through a reduction in the capacity of services to fewer customers at any given time, removing waiting areas, and accepting customers by appointment only, installing Plexiglas between service stations, and requiring all employees and customers to wear face masks at all times[32]. The results of this study indicate that increased outdoor airflow can reduce the risk of airborne infection transmission. For example, Salon 3 had the lowest outdoor airflow rate (3.72 m^3/min) among all of the salons and, subsequently, the highest risk of airborne infection transmission across both steady-state (Scenario 1 = 99.25%) and non-steady-state (Scenario 5 = 25.47%) scenarios, when no face mask-wearing was assumed. In comparison to Salon 12, which had the highest outdoor airflow rate (94.19 m^3/min), the risk of airborne infection transmission was the lowest among both steady-state (<17.54%) and non-steady-state (<1.19%) scenarios, when no face mask-wearing was assumed. It should be noted that Salon 12 utilized natural ventilation and did not have a dedicated exhaust. While this method of control is feasible in the summer months, this would not be effective in colder months. In a similar study focusing on the role of ventilation in the spread of COVID-19, it was concluded that reducing occupancy by 50% reduced the risk of airborne infection transmission by 6.7% based on a 90-minute exposure duration in a restaurant, with similar dimensions to the nail salons; however, it was also demonstrated in this study that increasing the ventilation rate by approximately 27% could achieve the same rates of airborne infection transmission risk reduction.[33]

4.4.2 Steady vs. Non- Steady state scenarios

In the steady- and non-steady-state scenarios, worst-case and best-case scenarios were primarily determined by exposure time to an infected person. In Scenario 3, in which two customers, one infected and one susceptible, enter the salon at the same time and both stay for 150 minutes, the airborne infection transmission risk increases substantially until the infector leaves but does not immediately drop to zero. In Scenario 4, in which an infected customer enters the salon and stays for 45 minutes, while one susceptible customer enters 30 minutes after the infected customer and stays for 60 minutes, the risk of airborne infection transmission was still high and ranged from >0.01% to 9.83% across salons. This finding may explain why the SARS-CoV-2 virus spread so quickly initially in densely populated cities around the world and should be a consideration as businesses reopen to the public. Merely permitting fewer customers may not sufficiently reduce the risk of airborne infection transmission without increasing the amount of outdoor airflow. If outdoor airflow remains the same, the rate at which customers enter the salon can be reduced so that fewer customers are in the salon when the concentration of infectious materials is at its highest before concentration decay begins. This can be achieved through appointments that stagger the arrival of customers over a given time.

4.4.3 The impacts of facemask use

The role of face mask-wearing was heavily contested at the onset of the pandemic but is now accepted as an efficacious measure to reduce the spread of COVID-19.[34–36] The results of this study demonstrated that a face mask worn by both infected and susceptible parties could substantially reduce the risk of airborne infection transmission, even when outdoor airflow rate was poor, and the duration of exposure was long. In the worst-case scenario of two employees, one infected and one susceptible, spending a full workday together and assuming that no other infected person enters the salon (i.e., Scenario 1), the risk of airborne infection transmission of the susceptible employee was reduced from an average of 79.71% when neither party wore a face mask to 26.97% when both parties wore a face mask, an almost 3-fold reduction in risk. Further, in Salon 3, which had the lowest outdoor airflow rate, wearing face masks reduced the risk of airborne infection transmission by 47.29% for Scenario 1. In a recent study of COVID-19 transmission in a hair salon, where two symptomatic, COVID-19-positive hair stylists served 139 clients, all wearing masks, over 15- to 45-minute periods (mean = 19.5 min), there were no reported positive cases within a 14-day period.[37]

One study estimated that had New York State met 100% face mask compliance on the first day of the shelter-in-place order, the cumulative mortality rate from COVID-19 could have been four times less; even a 50% compliance rate could have halved the number of deaths recorded.[36] Since SARS-CoV-2 can be transmitted via droplets during close contact, any face covering, including homemade cloth masks and surgical masks, that traps exhaled droplets can reduce the amount of infectious airborne particles emitted, as well as the amount that can be inhaled by a susceptible individual.

It is acknowledged that there are still gaps in the literature regarding the transmission of this novel human coronavirus. The value of the quanta generation rate (q) has varied among a few studies[30,38,39] and needs to be studied further. The value of q used in this study was derived from a novel approach based on the viral load emitted in saliva.[30] However, there may be more accurate values based on other approaches. In this study, we used a conservative value for the quanta reduction potential of face masks based on several studies. The risk of airborne infection transmission may vary significantly from the modeled results presented in this study when different types of face masks are utilized in different settings. In addition, we assumed one infected individual was present in each of the exposure scenarios. Future research should evaluate airborne infection transmission risk assuming multiple infected individuals are present in a confined space for a given period.

4.5 Conclusions

This study found that adequate outdoor airflow and adherence to wearing face masks can reduce the risk of airborne SARS-CoV-2 infection transmission in New York City nail salons. Increased outdoor airflow has the potential to reduce the risk of airborne infection transmission to approximately <1% when face masks are worn by all occupants of a confined space. Social distancing and reduction of contact time are also essential to reducing the risk of airborne infection transmission. As New York State continues to reopen gradually, it is imperative for individuals to continue observing social distancing and face mask-wearing requirements and for establishments to ensure that buildings are properly ventilated and are not overcrowded to mitigate potential airborne SARS-CoV-2 infection transmission risk.

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Declaration of Interest

AH and BP declare no conflicts of interest. AMI is currently employed by Cardno ChemRisk, a consulting firm that provides scientific advice to the government, corporations, law firms, and various scientific/professional organizations. The firm has been engaged by numerous companies to provide COVID-related toxicology, epidemiology, industrial hygiene, and health and safety advice. The time invested by AMI to write this paper was provided by his employer.

4.6 References

1. van Doremalen N, Bushmaker T, Morris DH, et al. Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1. *N Engl J Med*. 2020;382(16):1564-1567. doi:10.1056/NEJMc2004973
2. World Health Organization (WHO). Transmission of SARS-CoV-2: implications for infection prevention precautions. Published July 9, 2020. Accessed March 29, 2021. https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions
3. Otter JA, Donskey C, Yezli S, Douthwaite S, Goldenberg SD, Weber DJ. Transmission of SARS and MERS coronaviruses and influenza virus in healthcare settings: the possible role of dry surface contamination. *J Hosp Infect*. 2016;92(3):235-250. doi:10.1016/j.jhin.2015.08.027
4. US EPA O. List N: Disinfectants for Coronavirus (COVID-19). US EPA. Published March 13, 2020. Accessed August 22, 2020. https://www.epa.gov/pesticide-registration/list-n-disinfectants-coronavirus-covid-19
5. CDC. Coronavirus disease 2019 (COVID-19): How it spreads. Centers for Disease Control and Prevention. Published October 28, 2020. Accessed March 29, 2021. https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/how-covid-spreads.html
6. CDC. Coronavirus disease 2019 (COVID-19): Appendix A—Glossary of key terms. Centers for Disease Control and Prevention. Published May 29, 2020. Accessed August 22, 2020. https://www.cdc.gov/coronavirus/2019-ncov/php/contact-tracing/contact-tracing-plan/appendix.html
7. Lu J, Gu J, Li K, et al. COVID-19 Outbreak Associated with Air Conditioning in Restaurant, Guangzhou, China, 2020. *Emerg Infect Dis*. 2020;26(7):1628-1631. doi:10.3201/eid2607.200764
8. Yong SEF, Anderson DE, Wei WE, et al. Connecting clusters of COVID-19: an epidemiological and serological investigation. *The Lancet Infectious Diseases*. 2020;20(7):809-815. doi:10.1016/S1473-3099(20)30273-5
9. Moriarty LF, Plucinski MM, Marston BJ, et al. Public Health Responses to COVID-19 Outbreaks on Cruise Ships — Worldwide, February–March 2020. CDC Cruise Ship Response Team, California Department of Public Health COVID-19 Team, Solano County COVID-19 Team, eds. *MMWR Morb Mortal Wkly Rep 69(12):347-352*. 2020;69(12). https://stacks.cdc.gov/view/cdc/99479
10. Chu DK, Akl EA, Duda S, et al. Physical distancing, face masks, and eye protection to prevent person-to-person transmission of SARS-CoV-2 and COVID-19: a systematic

review and meta-analysis. *The Lancet*. 2020;395(10242):1973-1987. doi:10.1016/S0140-6736(20)31142-9
11. Lednicky JA, Lauzardo M, Fan ZH, et al. Viable SARS-CoV-2 in the air of a hospital room with COVID-19 patients. *International Journal of Infectious Diseases*. 2020;100:476-482. doi:10.1016/j.ijid.2020.09.025
12. Morawska L, Cao J. Airborne transmission of SARS-CoV-2: The world should face the reality. *Environ Int*. 2020;139:105730. doi:10.1016/j.envint.2020.105730
13. American Industrial Hygiene Association [AIHA]. *Reopening: Guidance for Hair and Nail Salons—Version 4.*; 2020. Accessed August 22, 2020. https://aiha-assets.sfo2.digitaloceanspaces.com/AIHA/resources/Reopening-Guidance-for-Hair-and-Nail-Salons_GuidanceDocument.pdf
14. Pavilonis B, Roelofs C, Blair C. Assessing indoor air quality in New York City nail salons. *JOURNAL OF OCCUPATIONAL AND ENVIRONMENTAL HYGIENE*. 2018;15(5):422-429. doi:10.1080/15459624.2018.1447117
15. Harrichandra A, Roelofs C, Pavilonis B. Occupational Exposure and Ventilation Assessment in New York City Nail Salons. *Ann Work Expo Health*. 2020;64(5):468-478. doi:10.1093/annweh/wxaa035
16. Basch C, Yarborough C, Trusty S, Basch C. Use of Protective Gloves in Nail Salons in Manhattan, New York City. *J Prev Med Public Health*. 2016;49(4):249-251. doi:10.3961/jpmph.16.017
17. New York State Governor's Office. Governor Cuomo Announces New York City Enters Phase III of Reopening Without Indoor Dining and Subject to State Guidance Today. Governor Andrew M. Cuomo. Published July 6, 2020. Accessed August 22, 2020. https://www.governor.ny.gov/news/governor-cuomo-announces-new-york-city-enters-phase-iii-reopening-without-indoor-dining-and
18. New York City Department of Health and Mental Hygiene. NYC Coronavirus Disease 2019 (COVID-19) Data. Published August 21, 2020. Accessed August 11, 2020. https://github.com/nychealth/coronavirus-data
19. Wells WF. Airborne Contagion and Air Hygiene. An Ecological Study of Droplet Infections. *Airborne Contagion and Air Hygiene An Ecological Study of Droplet Infections*. Published online 1955. Accessed March 29, 2021. https://www.cabdirect.org/cabdirect/abstract/19562701497
20. Rudnick SN, Milton DK. Risk of indoor airborne infection transmission estimated from carbon dioxide concentration. *Indoor Air*. 2003;13(3):237-245. doi:10.1034/j.1600-0668.2003.00189.x
21. Watanabe T, Bartrand TA, Weir MH, Omura T, Haas CN. Development of a dose-response model for SARS coronavirus. *Risk Anal*. 2010;30(7):1129-1138. doi:10.1111/j.1539-6924.2010.01427.x
22. ASTM International. *Standard Guide for Using Indoor Carbon Dioxide Concentrations to Evaluate Indoor Air Quality and Ventilation; Active Standard ASTM D6245. Developed by Subcommittee: D22.05.* American Society for Testing and Materials.; 2018.
23. Benbough JE. Some Factors Affecting the Survival of Airborne Viruses. *Journal of General Virology,*. 1971;10(3):209-220. doi:10.1099/0022-1317-10-3-209
24. Chatoutsidou SE, Lazaridis M. Assessment of the impact of particulate dry deposition on soiling of indoor cultural heritage objects found in churches and museums/libraries. *Journal of Cultural Heritage*. 2019;39:221-228. doi:10.1016/j.culher.2019.02.017

25. Zhu N, Zhang D, Wang W, et al. A Novel Coronavirus from Patients with Pneumonia in China, 2019. *N Engl J Med*. 2020;382(8):727-733. doi:10.1056/NEJMoa2001017
26. Fennelly KP, Nardell EA. The relative efficacy of respirators and room ventilation in preventing occupational tuberculosis. *Infect Control Hosp Epidemiol*. 1998;19(10):754-759. doi:10.1086/647719
27. Liang M, Gao L, Cheng C, et al. Efficacy of face mask in preventing respiratory virus transmission: A systematic review and meta-analysis. *Travel Med Infect Dis*. Published online May 28, 2020. doi:10.1016/j.tmaid.2020.101751
28. Nazaroff WW, Nicas M, Miller SL. Framework for Evaluating Measures to Control Nosocomial Tuberculosis Transmission. *Indoor Air*. 1998;8(4):205-218. doi:10.1111/j.1600-0668.1998.00002.x
29. Nicas M. An Analytical Framework for Relating Dose, Risk, and Incidence: An Application to Occupational Tuberculosis Infection. *Risk Analysis*. 1996;16(4):527-538. doi:10.1111/j.1539-6924.1996.tb01098.x
30. Buonanno G, Stabile L, Morawska L. Estimation of airborne viral emission: Quanta emission rate of SARS-CoV-2 for infection risk assessment. *Environment International*. 2020;141:105794. doi:10.1016/j.envint.2020.105794
31. Riley EC, Murphy G, Riley RL. Airborne spread of measles in a suburban elementary school. *Am J Epidemiol*. 1978;107(5):421-432. doi:10.1093/oxfordjournals.aje.a112560
32. CDC. Coronavirus disease 2019 (COVID-19): COVID-19 Employer Information for Nail Salons. Centers for Disease Control and Prevention. Published May 29, 2020. Accessed August 22, 2020. https://www.cdc.gov/coronavirus/2019-ncov/community/organizations/nail-salon-employers.html
33. Sun C, Zhai Z. The efficacy of social distance and ventilation effectiveness in preventing COVID-19 transmission. *Sustainable Cities and Society*. 2020;62:102390. doi:10.1016/j.scs.2020.102390
34. Feng S, Shen C, Xia N, Song W, Fan M, Cowling BJ. Rational use of face masks in the COVID-19 pandemic. *The Lancet Respiratory Medicine*. 2020;8(5):434-436. doi:10.1016/S2213-2600(20)30134-X
35. Lyu W, Wehby GL. Community Use Of Face Masks And COVID-19: Evidence From A Natural Experiment Of State Mandates In The US. *Health Affairs*. 2020;39(8):1419-1425. doi:10.1377/hlthaff.2020.00818
36. Ngonghala CN, Iboi E, Gumel AB. Could masks curtail the post-lockdown resurgence of COVID-19 in the US? *Mathematical Biosciences*. Published online August 18, 2020:108452. doi:10.1016/j.mbs.2020.108452
37. Hendrix MJ. Absence of Apparent Transmission of SARS-CoV-2 from Two Stylists After Exposure at a Hair Salon with a Universal Face Covering Policy — Springfield, Missouri, May 2020. *MMWR Morb Mortal Wkly Rep*. 2020;69. doi:10.15585/mmwr.mm6928e2
38. Dai H, Zhao B. Association of the infection probability of COVID-19 with ventilation rates in confined spaces. *Build Simul*. Published online August 4, 2020. doi:10.1007/s12273-020-0703-5
39. Zemouri C, Awad SF, Volgenant CMC, Crielaard W, Laheij AMGA, de Soet JJ. Modeling of the Transmission of Coronaviruses, Measles Virus, Influenza Virus, Mycobacterium tuberculosis, and Legionella pneumophila in Dental Clinics. *J Dent Res*. 2020;99(10):1192-1198. doi:10.1177/0022034520940288

Chapter 5 : Conclusions

This dissertation aimed to address gaps in the literature relevant to airborne chemical exposures that nail salon workers face in the occupational setting and further explore the role of ventilation in mitigating those exposures. Chapter 2 of this dissertation characterized the exposures by systematically reviewing the peer-reviewed literature of nail salon research conducted in the United States. Chapters 3 and 4 evaluated the effect of ventilation on indoor air pollution. Chapter 3 was an analysis of how the rate of air exchanges affects contaminant levels, and chapter 4 used the ventilation rates in chapter 3 to model the transmission potential of SARS-CoV-2 infections.

5.1 Summary of results: Aim 1

Nail salons workers are exposed to chemicals that cause acute and chronic health outcomes. Most of the chemicals are volatile, and once airborne, workers are exposed through inhalation and dermal contact. This research only focused on airborne exposure.

- Seventeen studies were included in the systematic review from a total of 2,950 studies. Three studies came from a randomized controlled trial investigating the association between workplace health and safety training and indoor air pollution reduction. Fourteen studies characterized exposure to indoor air pollutants using passive and active environmental monitoring.
- The environmental monitoring studies used convenience sampling and collected both area and personal air measurements. There was a moderate risk of bias when all of these studies or assessed. The intervention studies used randomized sampling, and there was generally a very low risk of bias in these studies. Overall, there was a moderate level of bias, and the conclusions can be considered valid.

- The exposure assessment studies found that nail salon workers were routinely exposed to volatile organic compounds, semi-volatile compounds, and particulate matter. Common chemicals found included acetone, acetonitrile, toluene, formaldehyde, isopropyl alcohol, methyl methacrylate, and ethyl methacrylate. The source of these chemicals includes nail polish, new polish remover, thinners, artificial acrylic nails, gels, and powders.
- Short-term health effects associated with exposure to these chemicals include headaches, nausea, dizziness, neurocognitive impairment, irritation of the skin and mucosal membranes, and respiratory irritation. Long-term health effects include chemical allergies and sensitization, reproductive and developmental effects, and liver and kidney damage.
- Due to greater interpersonal variability, personal air measurements generally were higher than area measurements when both were taken. Over the past few decades, the trend in contaminant levels has indicated a general decline, potentially due to the substitution of harmful products or engineering controls to reduce indoor air pollution.
- Two intervention studies showed that worker health and safety training reduced one or more indoor air pollutants and therefore, exposure. The third study did not find improvements in indoor air quality even though workers self-reported opting for less toxic products and using PPE. This discrepancy in the results is potentially due to measurement error.

5.2 Summary of results: Aim 2

In 2015, New York State enacted new ventilation regulations to protect employees and clients from exposure to chemicals used in the salons. This study measured the temporal variability of common air pollutants found in nail salons and assessed compliance with ventilation requirements.

- Across all salons (N=12), daily average customer volume was similar, and the day of the week was not a predictor of indoor air quality. Most salon owners/managers (58%) did not have or did not operate their ventilation systems according to NYS regulations. Of the salons that had a ventilation system installed, only five managers indicated salon air was exhausted directly outside, and no salons surveyed had LEV ventilation installed.
- The average concentration of carbon dioxide (CO_2) and total volatile organic compounds (TVOCs) across the three days was 1261ppm and 33ppm, respectively. Chemical-specific air sampling showed low to non-detectable levels across all salons.
- Only three salons (1, 8, and 9) out of 12 were compliant with the GEV requirements of 25 cfm of outdoor airflow, air exhausted directly outdoors, and exhaust used all day. These three salons also had no detectable amounts of MMA or toluene and had roughly half the concentrations of TVOC (16 ppm to 33 ppm) compared to salons that did not meet the requirements. Additionally, compliant salons had double the number of average services performed than salons that were not, 83 to 42. Two salons also met the minimum outdoor airflow guidelines (32 cfm and 322 cfm), but the primary ventilation source was from open windows and did not have a dedicated exhaust installed.

5.3 Summary of results: Aim 3

Airborne infection transmission risk was modeled assuming five realistic exposure scenarios using previously estimated outdoor airflow rates for 12 New York City nail salons. Additionally, the impact of face mask-wearing by occupants on airborne infection transmission risk was also evaluated.

- The risk of airborne infection transmission across all salons and all exposure scenarios when not wearing face masks ranged from <0.015% to 99.25%, with an average airborne infection transmission risk of 24.77%.
- Wearing face masks was estimated to reduce airborne infection transmission risk between <0.01% to 51.96%, depending on the salon, with an average airborne infection transmission risk of 7.30% across all salons.
- Increased outdoor airflow rates in nail salons were generally strongly correlated with decreased average airborne infection transmission risk.
- The results of this study indicate that increased outdoor airflow rates and the use of face masks by both employees and customers could substantially reduce SARS-CoV-2 transmission in New York City nail salons.

5.4 Significance of findings and opportunities for future research

The studies that comprise this dissertation add to the literature on occupational health hazards that nail salon workers are exposed to and contribute novel information regarding the role of ventilation in mitigating airborne chemical and biological exposures. The OHAT framework used to conduct the systematic review in aim 1 allowed for a scientifically rigorous and objective protocol to be developed. The study-level health effects data and risk-of-bias assessment features allow appraisal of potential biases in each included study's designs to make the overall assessment sound, objective, and reproducible. Unlike the Cochrane method for systematic review, the OHAT method allowed for evaluating and synthesizing non-clinical, environmental monitoring data. Several studies have been conducted on nail salons in the United States with many different focuses and analyses. This systematic review provides a comprehensive overview of the air monitoring assessments conducted in the nail salons, collated into a single study for easy reference.

These results illustrate the hazards that nail salon workers face and the burden of making a livable wage while experiencing many health symptoms. This approach was able to identify research gaps in the current evidence and understanding of the issue of exposure in nail salons.

Moreover, important suggestions could be made about improvements to existing methods for more robust studies in the future, e.g., utilizing less biased sampling methods when surveying participants. This systematic review can be a great starting point to build on existing studies that may have been narrow in scope. Additionally, it can be used to design studies for which no information exists about a particular chemical exposure, a health effect, or an exposure mitigation measure. Perhaps the biggest call for research is to have well-designed, prospective epidemiological studies to explore in greater detail the association between exposures to different chemicals and documental health outcomes.

One of the key aspects of aim 2 in this dissertation is the time-weighted averages of indoor air pollutants measured over three days to characterize temporal variations across the salons. Though the day of the week was not a predictor of indoor air quality, there is an opportunity to repeat this study, measuring all days of the week and a great number of salons for a more robust analysis. Time-weighted averages were able to capture the contaminant levels for the entire business days, and the collection of area samples rather than personal samples was subject to less variability. The use of CO_2 as a proxy for ventilation rates is an excellent way for salons to monitor their indoor air quality by simply measuring CO_2 using small, inexpensive monitors. Ventilation can be adjusted accordingly to increase the rate air is being exhausted from the salon. One of the main reasons for measuring ventilation in aim 2 was to compare the existing state of indoor air quality in nail salons with their various ventilation methods to the requirements according to the NYS regulation. While the regulation is well-intended to protect worker and customer health, there is concern that the installation and operation of local and general exhaust ventilation will be expensive and burdensome for small nail salon owners or the building owner. The research in aim 3 was novel and timely and presented useful information for nail salons moving forward in the pandemic. Using actual ventilation rates that were previously measured in aim two and the well-known Wells-Riley equation made the modeling of transmission rates more robust and accurate. However, there is a need to refine further the quanta generation rate (q) for SARS CoV-2.

Additionally, analyzing the effects of mask use during a time of great controversy and uncertainty about masks' efficacy in protecting against viral transmission was another significant aspect of this research. Though aim 3 focused on nail salons, the discussion of transmission risk could translate to other similar personal care services (hair salons, beauty and massage parlors, barbershops, and spas) that will resume as the pandemic wanes. Five realistic exposure scenarios illustrated transmission risk, but an infinite number of scenarios can be explored using the modeling utilized in aim 3.

5.5 Public health Relevance

This dissertation fills research gaps in many different realms of public health but most notably environmental health and occupational health and safety. Specific areas of public health relevance are indoor air quality, occupational exposures, worker health, disease transmission risk, the current SARS CoV-2 pandemic, and workplace hazards mitigation. Aim 1 characterized airborne exposures in nail salons and discussed the associated health effects. Baseline data must be collected and assessed to inform the mitigation process to remove or reduce hazards. While similar studies to the ones included in aim 1 have been conducted outside of the United States, there is a need for locally relevant public health data to inform health policy. This information could also be highly useful for nail salon owners to protect their employees and for nail salon workers to adopt safer workplace behaviors to reduce their exposures and improve their health.

Aim 2 has specifically added to the literature on the New York geographic area where the nail salon industry is rapidly growing, but only a few studies have been done. This research advanced the knowledge on the role of ventilation in controlling indoor air pollution and, in the absence of functioning exhaust ventilation, using proxy measurements to indicate poor air quality. In aim 2, we found that even though none of the salons installed exhaust ventilation systems, some of them still had ventilation rates comparable to mechanical ventilation. Nail salons that do not have mechanical ventilation often rely on doors or windows to supply fresh air into the salon. This temporary solution is often not practical in the winter months in temperate regions. The number of occupants in the salons did not increase the CO_2 concentrations as we hypothesized but decreased it. We suspected the frequent opening of the doors from inbound and outbound customers allowed pollutants to escape. If this simple inadvertent means of ventilation helped curb indoor air pollution levels, then the levels of ventilation stipulated in the NYS regulation may not be necessary, and salon managers can sustainably operate the ventilation system during off peak hours when air quality might be noticeably uncomfortable. Aim 3 is one of many studies that will contribute to our understanding of the pandemic's impacts in the coming years. This information could guide the efforts to reopen businesses and return to some sense of normalcy as small business owners and employees grapple with the immense economic and psychological impacts. This paper's results can also help inform consumers of these personal care services whether the risks involved are worth accessing these services. This study has echoed many others' findings on the efficacy of different face coverings to reduce various diseases' airborne transmission. Given all of these findings, these studies all contribute to the public health knowledge base and are timely and relevant to New York City and many other major cities in the United States.

5.6 Limitations

While the methods used for the studies in this dissertation were designed using the best available design aspects, there are a few limitations to note. In aim 1, though not explicitly stated in the two intervention studies, it is suspected that participants were not randomly chosen for all the intervention or all the control groups and may have been selected from groups subjected to other types of interventions. Additionally, all the included environmental monitoring studies utilized convenience sampling for participating nail salons and workers. Therefore, the generalizations that are made from the findings can only be applied to the sampled population. Randomization reduces biases making the intervention's outcome unpredictable and generalizable to other populations.[1] Additionally, another limitation is excluding studies that may have presented more evidence for the association between the documented chemicals and observed health effects.

The nail salons sampled in aim 2 were done using convenience sampling, which means that the results' implications in aims 2 and 3 can only apply to the sample and not be generalized to other populations.[2] Though convenience sampling has many weaknesses, it was the best available sampling method given the challenge of finding willing participants. In this study and many others done before in other states, the population of interest usually comprises mostly Asian American salon workers. There is a missed opportunity to survey other ethnic groups with unique vulnerabilities, behaviors, and cultures that may affect the health and safety practices of the nail salon environment. The value of the quanta generation rate (q) used to model transmission potential of SARS-CoV 2 in aim 3 has varied among a few studies[30,38,39] and needs to be studied further. The value of q used in this study was derived from a novel approach based on the viral load emitted in saliva[30,] but there may be more accurate values based on other approaches. This study used a conservative value for face masks' quanta reduction potential based on several studies. The risk of airborne infection transmission may vary significantly from the modeled results presented in this study when different types of face masks are utilized in different settings. Also, we assumed one infected individual was present in each of the exposure scenarios. Future research should evaluate airborne infection transmission risk assuming multiple infected individuals are present in a confined space for a given period.

5.7 References

1. Kang M, Ragan BG, Park J-H. Issues in Outcomes Research: An Overview of Randomization Techniques for Clinical Trials. *J Athl Train*. 2008;43(2):215-221. Accessed January 24, 2021. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2267325/
2. Bornstein MH, Jager J, Putnick DL. Sampling in Developmental Science: Situations, Shortcomings, Solutions, and Standards. *Dev Rev*. 2013;33(4):357-370. doi:10.1016/j.dr.2013.08.003

Appendices

Aim 1

Appendix A- Search terms syntax for PubMED

(nail salon worker OR nail salon technician OR nail salon employee OR nail salon*[tiab])

AND
(Occupational exposure[mh] OR occupational diseases[mh] OR occupation OR workplace OR work-related[tiab] OR exposure*[tiab] OR exposed[tiab] OR chemical exposure)

AND
(ethyl acetate OR butyl acetate OR isopropyl alcohol OR ethyl alcohol OR acetone OR toluene OR xylene OR benzene OR Ethyl methacrylate OR Methyl methacrylate OR butyl methacrylate OR Methyl ethyl ketone OR Ethyl cyanoacrylate OR Acetonitrile OR formaldehyde OR Methacrylic acid OR Dibutyl phthalate)

AND
(adverse health*[tiab] OR health impacts OR symptoms**[tiab] OR** irritation OR asthma OR eye Irritation OR nose irritation OR throat irritation OR headache OR CNS syndrome OR central nervous system syndrome OR corneal damage OR reproductive effects OR upper respiratory system OR stomach OR Lung fibrosis OR occupational carcinogen OR carcinogen OR cough OR liver damage OR anemia OR oxidative stress OR DNA damage OR genetic damage)

Appendix B- Citation List of Included studies

1. Alaves VM, Sleeth DK, Thiese MS, Larson RR. Characterization of indoor air contaminants in a randomly selected set of commercial nail salons in Salt Lake County, Utah, USA. International Journal of Environmental Health Research. 2013;23(5):419-433. doi:10.1080/09603123.2012.755152

2. Ceballos DM, Craig J, Fu X, et al. Biological and environmental exposure monitoring of volatile organic compounds among nail technicians in the Greater Boston area. Indoor Air. 2019;29(4):539-550. doi:10.1111/ina.12564

3. Craig JA, Ceballos DM, Fruh V, et al. Exposure of Nail Salon Workers to Phthalates, Di(2-ethylhexyl) Terephthalate, and Organophosphate Esters: A Pilot Study. Environmental Science & Technology. 2019;53(24):14630-14637. doi:10.1021/acs.est.9b02474

4. Estill CF, Mayer A, Slone J, et al. Assessment of triphenyl phosphate (TPhP) exposure to nail salon workers by air, hand wipe, and urine analysis. International Journal of Hygiene and Environmental Health. 2020;231:113630. doi:10.1016/j.ijheh.2020.113630

5. Froines JR, Garabrant DH. Quantitative Evaluation of Manicurists Exposure to Methyl, Ethyl and Isobutyl Methacrylate During Production of Synthetic Fingernails. Applied Industrial Hygiene. 1986;1(2):70-74. doi:10.1080/08828032.1986.10390471

6. Garcia E, Sharma S, Pierce M, et al. Evaluating a County-Based Healthy Nail Salon Recognition Program. American Journal Of Industrial Medicine. 2015;58(2):193-202. doi:10.1002/ajim.22379

7. Goldin LJ, Ansher L, Berlin A, et al. Indoor Air Quality Survey of Nail Salons in Boston. Journal of Immigrant And Minority Health. 2014;16(3):508-514. doi:10.1007/s10903-013-9856-y

8. Harrichandra A, Roelofs C, Pavilonis B. Occupational Exposure and Ventilation Assessment in New York City Nail Salons. Ann Work Expo Health. 2020;64(5):468-478. doi:10.1093/annweh/wxaa035

9. Hiipakka D, Samimi B. Exposure of acrylic fingernail sculptors to organic vapors and methacrylate dusts. Am Ind Hyg Assoc J. 1987;48(3):230-237. doi:10.1080/15298668791384670

10. Lamplugh A, Harries M, Xiang F, Trinh J, Hecobian A, Montoya LD. Occupational exposure to volatile organic compounds and health risks in Colorado nail salons. Environmental Pollution. 2019;249:518-526. doi:10.1016/j.envpol.2019.03.086

11. Ma GX, Wei Z, Husni R, et al. Characterizing Occupational Health Risks and Chemical Exposures Among Asian Nail Salon Workers on the East Coast of the United States. Journal of Community Health. 2019;44(6):1168-1179. doi:10.1007/s10900-019-00702-0

12. Pavilonis B, Roelofs C, Blair C. Assessing indoor air quality in New York City nail salons. Journal Of Occupational And Environmental Hygiene. 2018;15(5):422-429. doi:10.1080/15459624.2018.1447117

13. Quach T, Gunier R, Tran A, et al. Characterizing Workplace Exposures in Vietnamese Women Working in California Nail Salons. American Journal Of Public Health. 2011;101(1):S271-S276. doi:10.2105/AJPH.2010.300099

14. Quach T, Varshavsky J, Von Behren J, et al. Reducing chemical exposures in nail salons through owner and worker trainings: an exploratory intervention study. Am J Ind Med. 2013;56(7):806-817. doi:10.1002/ajim.22146

15. Quach T, Von Behren J, Nelson DO, et al. Evaluating an owner-to-worker training intervention in California nail salons using personal air monitoring. Am J Ind Med. 2018;61(10):831-841. doi:10.1002/ajim.22897

16. Spencer A, Estill C, McCammon J, Mickelsen R, Johnston O. Control of ethyl methacrylate exposures during the application of artificial fingernails. American Industrial Hygiene Association Journal. 1997;58(3):214-218.

17. Zhong L, Batterman S, Milando CW. VOC sources and exposures in nail salons: a pilot study in Michigan, USA. International Archives of Occupational and Environmental Health. 2019;92(1):141-153. doi:10.1007/s00420-018-1353-0.

Appendix C- Defined acronyms in table 2.3 for Craig et al., (2015)

Compound name	Acronym used in table 2.3
Phthalates	
butylbenzyl phthalate	BBzP
di-*n*-butyl phthalate	DBP
di-*iso*-butyl phthalate	DiBP
diethyl phthalate	DEP
dimethyl phthalate	DMP
di(2-ethylhexyl) phthalate	DEHP
di-isononyl phthalate	DiNP
Phthalate Alternatives	
diethylhexyl adipate	DEHA
trioctyltrimellitate	TOTM
Organophosphate Esters	
tris(1-chloro-2-propyl) phosphate	TCIPP
tris(2-chloroethyl) phosphate	TCEP
tris(1,3-dichloro-2-propyl) phosphate	TDCIPP
triphenyl phosphate	TPHP