CHARACTERISATION OF EXPOSURE TO VOLATILE ORGANIC COMPOUNDS ASSOCIATED WITH NAIL TREATMENTS IN NAIL SALONS

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Declaration

I **(Mosima Success Letsoalo) with the student ID number (832203)**, declare that this research project entitled *"Characterisation of exposure to volatile organic compounds associated with nail treatments in nail salons"* is my own, unaided work undertaken under supervision of Mrs Keretetse and Dr Masekameni. It is being submitted in partial fulfilment for the degree of Master of Science in Medicine (Exposure Science) at the School of Public Health, University of the Witwatersrand, Johannesburg. This work has not been submitted before for any degree or examination at any other University. The author designed the study, conducted data collection as well as data analysis and write-up of this research report. As per the plagiarism policy, a plagiarism declaration form is signed and attached as Appendix A.

__ Mletsoalo. ____________________________

Signature of candidate

____23_____day of _____June____________2021______in ___Pretoria _________

Dedication

I would like to dedicate this research report to my parents, Mr Matome Letsoalo, and Mrs Kobela Letsoalo as well as my brothers (Ngoako and Thapelo Letsoalo) for their support, care and prayers that kept me going during this journey. Also dedicate this report in honour of my late grandmothers (Mantsha Letsoalo, Mosima Rapotu, and Raesetŝa Bopape) I will always remember their guidance and words of encouragement that I can do anything that my heart desire.

Abstract

Workers in the nail salon industry are exposed to various volatile organic compounds (VOCs) in their line of duty. Exposures are due to the chemicals such as formaldehyde, toluene, xylene, and acrylates contained in the nail treatment products. Such chemicals have been linked to acute irritation of the skin and mucous membranes to more severe and irreversible cancer-related effects. Despite the proven correlation between VOC exposure and negative health effects in the nail salon industry, there have been very few exposures profiled studies done in the South African context. Additionally, limited studies on exposure to nail salon chemicals have led to the industry being regarded as "safe" irrespective of contradictory findings in numerous studies. Therefore, the study characterised and determined exposure to eight VOCs and subsequently determined the associated health risk amongst nail technicians. The study was conducted in a controlled laboratory environment which was tailored to mimic real-world scenarios in the South African informal nail salon setting. A miniature practice hand was procured and used for laboratory simulation resembling a human hand. Exposure monitoring was done using a MiniRAE 3000 Photoionization Detector (PID) to measure VOC emitted during nail treatments. The PID instrument probe was placed within the 30 cm breathing circumference of the receptor (nail technician) to detect the VOC concentration in the microenvironment. Two exposure scenarios namely, nail treatment without ventilation (scenario A) and nail treatment with ventilation (scenario B) were used to monitor two types of nail treatments (acrylic as well as buff and paint). Furthermore, the VOC concentrations were used to obtain dose estimates. Data from the PID instrument was exported to a Microsoft Excel spreadsheet. All outliers were removed from the data and correction factors applied. Thereafter, averages and statistical tests (student F- test and T-test) were calculated.

The average concentrations were further used to obtain the dose estimates expressed as hazard quotients for the health risk assessment. Single nail treatment averaged TVOC emissions of the acrylic as well as the buff and paint nail treatments in exposure scenario A were 604,26 mg/m^3 and 301,84 mg/m^3, respectively. Whereas, in exposure scenario B, the averaged TVOC emissions were 304,67 mg/m^3 and 82,15 mg/m^3 for acrylic as well as buff and paint nail treatments, respectively. Despite the low VOC emissions in the buff and paint nail treatments under both exposure scenarios, the treatment was classified as a high-risk situation. This was mainly because of the increased exposure duration and health outcomes (ranging from irritation and carcinogenic effects) associated with the chemicals contained in the products. Moreover, a more than 70% reduction in the VOCs emission under exposure scenario B was observed.

Given that on average, nail technicians provide seven (7) treatments per shift and the results showed TVOC emissions of 3237,71 mg/m^3 and 2518,88 mg/m^3 for acrylic as well as buff and paint nail treatments, respectively. In addition, associated with the high acrylic TVOC emissions, methyl methacrylate and ethyl methacrylate were shown to have high emissions. For risk characterisation, all selected VOCs were categorised as non-carcinogenic based on toxicological data. Furthermore, acetone, toluene, methyl methacrylate, and ethyl acetate showed the risk of developing health effects (HQ>1) amongst nail technicians. Toluene was of concern due to carcinogenic effects. On the other hand, xylene showed that despite the risk of exposure amongst nail technicians, females were at an increased risk of developing health effects (HQ=1,1) as opposed to males (HQ=0,9). Overall, there is a need to implement ventilation measures to reduce exposure as highlighted in this study. Furthermore, this study showed the importance of obtaining exposure data to estimate risk instead of relying solely on environmental concentration.

Keywords: TVOC, nail treatment, acrylic, buff, and paint

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CDI	Chronic daily intake
CF	Correction factor
DBP	Dibutyl phthalate
DNA	Deoxyribonucleic acid
ED	Exposure days
HQ	Hazard Quotient
Mg/m^3	milligram per cubic metre
MMA	Methyl methacrylate
NIOSH REL	National Institute for Occupational Safety & Health Recommended Limit
PID	Photoionization detector
PPB	Parts per billion
PPM	Parts per million
RfD	Reference dose
SANAS	South African National Accreditation System
TVOC	Total volatile organic compounds
US EPA	United States Environmental Protection Agency
VOC	Volatile organic compound

Glossary

Breathing zone- referred to as a virtual space within a 0.3 m (or 10 inch) radius of the nose and mouth

Chronic daily intake – the intake of a chemical, expressed in terms of the mass of the substance, contacted per unit body weight per unit time averaged for over 25 years for an occupational exposure.

Correction factor- refers to the response of the isobutylene calibrated PID to the equal concentration of the chemical measured.

Dose- to the amount of chemical that enters the body of the receptor after crossing an exposure surface.

Environmental concentration- the amount of a chemical available in the environmental compartment such as air.

Experimental studies- refers to the studies conducted in a laboratory setting where several variables such as temperature, humidity, airflow and other VOC sources can be controlled.

Fate- is the distribution of the chemical or its metabolites in the body because of transport, transformation, or degradation.

Field-based studies- - refers to research studies conducted by observing and interacting with study participants in their natural/real-world settings.in a real-world setting.

Hazard Quotient- it is the ratio of exposure to a substance where no health effects are expected.

Microenvironment- the surrounding environment of the receptor where a contact between the chemical and receptor is likely to occur.

Monitoring- real-time assessment of the concentration of a chemical substance in the environment using direct reading instruments such as PID.

Nearest field- often referred to as the breathing zone. It is the virtual zone close to the exposure surface which is considered to be the exposure surface.

Health risk assessment- the calculation and expression of risk using various descriptor values to approximate the possible health outcomes.

Receptor- an entity that is exposed to a substance.

Reference concentration- refers to an estimate of continuous inhalation exposure within a human population that is likely to have health risk during the population's lifetime.

Sample- a separated portion of an ambient atmosphere subsequently analysed to determine concentration of contaminant(s).

Sampling – is the time-aggregated collection/acquiring of a sample in the field using any variety of pollutant collection devices such as a filter, aqueous absorbents, solid adsorbents, etc. This is done by personal or area sampling often requiring offline analysis.

CHAPTER ONE – INTRODUCTION

This chapter gives an overview of the nail salon industry and possible occupational exposures. The chapter emphasises nail treatment activities focusing on volatile organic compounds exposure and potential health effects. The research problem statement, the aim of the study, the domain of the study, and the specific research objectives are presented. Lastly, the justification of the study and the scope of the study are highlighted.

1.1 Background

Globally, the nail salon industry is a fast-paced expanding industry. However, despite the rapid growth of the industry, there is still some occupational health neglect, especially because very low concentrations of hazardous chemicals are used compared to other well-studied industries e.g. mining and petrochemical (Gjølstad *et al*., 2006; Grešner *et al.*, 2017). Thus for this industry, information on chemical exposure and biomonitoring is rather limited (Harris-Roberts *et al.*, 2011; Moise *et al.*, 2019; Quiros-Alcala *et al.*, 2019; Ssempebwa *et al.*, 2019).

Such limitations have led to the rapid increase in occupational exposure induced negative health implications amongst nail technicians (Moise *et al.*, 2019; Ssempebwa *et al.*, 2019). A lot of attention has shifted towards the nail salon industry due to the hazardous chemical composition of the products used in nail treatments that tend to have adverse health effects. Again, of concern is that 96% of nail salon workers are women and normally within the reproductive age (Halliday-Bell *et al.*, 2009; Quach *et al.*, 2015; Centre of Disease Control, 2018; Seo *et al.*, 2019) thus making them more vulnerable to lifetime deficiencies.

In the nail salon industry, there are various activities referred to as nail treatments namely application of nail polishes, nail elongation, and inserting artificial nails just to name a few. Notable is that the nail treatments are mostly dependent on the latest fashion trends and individual preferences (Ssempebwa *et al.*, 2019). Additionally, Yang *et al.*, (2010) highlighted that acrylic nail sculpting and gel nail polish procedure showed the highest levels of exposure. Studies by Yang *et al.*, (2010) as well as Roelofs and Do (2012) highlighted that even though volatile organic compounds (VOCs) are present during the nail treatment processes and might account for the high levels of exposure but so are other chemicals. These studies further elaborated that there is possible overexposure among nail technicians due to chemical mixtures.

The chemical mixtures comprise of ultrafine particles especially during nail filing, VOCs from the products' ingredients as well as other reactive gases (Pavilonis *et al*., 2018). Nail treatments require the use of multiple nail products simultaneously. Consequently, these results in cumulative exposure from chemical mixtures occurring through multiple routes and causing toxic effects contrary to single chemical exposure (Yang *et al.*, 2010; Ssempebwa *et al.*, 2019). In the South African context, the risk of overexposure may be higher given that nail technicians often share a workplace with hairdressers and sometimes perform both hair and nail treatments, especially in the informal sector. Therefore, the sharing of workspace and dual roles increases occupational exposure amongst nail technicians (Halliday-Bell *et al.*, 2009). There are hazardous chemicals such as formaldehyde, dibutyl phthalate (DBP), acetone, toluene, etc. that are contained in the products used for the nail treatments like nail polish, nail polish removers, acrylic polymers, hardeners, primers, dehydrators, nail tip adhesives, artificial nail removers, and disinfectants. Of concern, is that such hazardous chemicals are used in the nail technicians' nearest field also referred to as the breathing zone (Gjølstad *et al.*, 2006; Yang *et al.*, 2010; Pavilonis *et al.*, 2018). This has negative health effects ranging from acute respiratory discomforts to chronic respiratory disorders and other disorders linked to organs malfunctioning (Yang *et al.*, 2010; Huzar *et al.*, 2011; Grešner *et al.*, 2016; Ceballos *et al.*, 2019; Quiros-Alcala *et al.*, 2019; Ssempebwa *et al.*, 2019).

Based on nail salon industry-related epidemiological studies (Manikantan *et al.*, 2010; Grešner *et al.*, 2016) there is a link between exposure to hazardous chemicals especially VOCs, and health outcomes such as oxidative stress, deoxyribonucleic acid (DNA) damage, deregulation of cellular antioxidant defence and trigger processes leading to possibly carcinogenesis. In addition, vivo studies show that there is a potential genotoxic impact of VOCs on the cells and make-up of animals specifically and extrapolation to fit the impact on human cells can be achieved (Hadei *et al.*, 2018).

1.2 Literature review

Globally, about 85-90% of women make use of nail salon services (Goldstein Research, 2018; Reinecke and Hinshaw, 2020). This reflects the importance of how women have continuously used nail cosmetics for enhancing the aesthetic appearance of nails. The enhancement involves nail technicians using VOC-enriched nail products during various nail treatments. Exposure to these nail products may result in health effects ranging from irritation to carcinogenic effects. Therefore, the desired aesthetic appearance of clients' nails comes with undesired detrimental health effects for nail technicians.

1.2.1 Nail treatment processes and products used

There are different types of nail treatments done in nail salon settings involving the use of a variety of nail products. Treatments range from the simple application of nail polish to artificial acrylic nail sculpting. For example, artificial acrylic nail sculpting involves the use of a powder polymer and a liquid monomer mixture molded onto the nail tips, and that gives rise to a chemical process called polymerization in order to create the desired artificial nails (Reinecke and Hinshaw, 2020). Furthermore, drying of the artificial nail is done with either air-drying or the use of ultraviolet (UV) light. Similar to acrylic nail treatment, the gel nail polish application method involves coating nails with methacrylate oligomers which are premixed then cured with UV light (Gjølstad, Thorud and Molander, 2006; Reutman *et al.*, 2009). Buff and paint nail treatment is a treatment where nail polish is applied to the client's nails and either air dried or use UV light to aid the drying process (Gatica-Ortega *et al.*, 2017). In this treatment, the nail technician uses a nail remover where acetone is a major compound to clean the nails or remove old nail polish before fresh coating the nails with nail polish. Nail polishes consist of a mixture of chemicals but mostly found in formaldehyde, xylene, toluene, and acetates (Reutman *et al.*, 2009; Roelofs and Do, 2012).

During these treatments, the majority of the chemicals exposures in a form of VOCs from nail polishes, acrylic monomers and polymers, nail polish removers, artificial nail tip adhesives, glues, and nail hardeners are emitted (Arora and Tosti, 2017; Pavilonis *et al.*, 2018; Ceballos *et al.*, 2019; Heaton *et al.*, 2019; Seller *et al.*, 2019; Zhong et al., 2019). Based on findings from various studies, VOCs are mostly emitted during application of the acrylic monomer and polymer as well as filing and shaping of artificial nails (Alaves *et al.*, 2013; Grešner *et al.*, 2017; Chang *et al.*, 2018; Pavilonis *et al.*, 2018; Ceballos *et al.*, 2019). Yang *et al.*, (2010) found that acrylic nail sculpting and gel nail polish treatments showed the highest exposure to VOCs amongst nail technicians as compared to other treatment methods.

1.2.2 Factors influencing the fate and transport of VOCs

In the case of nail treatments: VOCs are readily released, diffused into the air, and become available in the nail technicians' microenvironment (Tsigonia *et al.*, 2010; Baghani *et al.*, 2018). Such VOC emissions in the microenvironment often result in the nail technicians' immediate susceptibility to exposure. Additionally, the concentration of compounds in the air is dependent on the number of treatment activities carried out (Tsigonia *et al.*, 2010). Environmental factors such as ventilation, crowded spaces, temperature and humidity influence the emissions and distribution of the VOCs (Tsigonia *et al.*, 2010; Baghani *et al.*, 2018; Moradi *et al.*, 2019).

Additionally, the study by Baghani *et al.*, (2018) concluded that ventilation may lead to lowered VOC concentration. However, in nail salons with natural ventilation, the air exchange was no adequate to decrease concentration levels. Furthermore, the study findings did not consider the number of treatments, the duration of the treatments, or other environmental parameters like temperature (Baghani *et al.,* 2018). The omission of this critical information means there will be high uncertainty regarding exposure. This often leads to inaccurate or biased estimates of exposure. This is because the number of treatments and duration helps in factoring in the time-weighted exposure whereas the environmental parameters inform on the fate and transport of the VOCs. Lastly, such information is important to account for variation over time and where an intervention can be better suited.

1.2.3 Toxico-kinetics and biotransformation properties of VOCs

Rappaport *et al*., (2005) and Coecke *et al.*, (2013) defined toxicokinetics as an endpoint that informs the fate and distribution of a chemical substance and its metabolites within the body. Furthermore, Rappaport *et al*., (2005) and Coecke *et al.*, (2013) elaborated that this provides information on the toxicological properties as well as the relationship between environmental concentration and internal dose within a receptor.

Exposure to VOCs can occur through inhalation and skin contact (Montero-Montoya *et al*., 2018). This means that there is an interaction between the VOCs and either the respiratory organ or skin of the receptor, resulting in the internal dose. For skin contact, the increase in the absorption of the VOCs is often dependent on the physical state of the skin i.e., dryness and abrasion. VOCs' lipophilic characteristics make it easier for the VOCs to pass through biological membranes and transform into metabolites (Montero-Montoya *et al*., 2018).

1.2.4 Health effects associated with VOCs emissions among nail technicians

There are acute effects associated with VOC exposure such as skin, eye and respiratory irritation as well as headaches reported in a number of studies (Ronda *et al*., 2009; Tsigonia *et al.*, 2010; Quach *et al.*, 2013; Nilsson *et al.*, 2015; Arora and Tosti, 2017; Hadei *et al.*, 2018; Shendell *et al.*, 2018; Lamplugh *et al.*, 2019; Quiros-Alcala *et al.*, 2019; Seller *et al.*, 2019; Ssempebwa *et al.*, 2019). Moreover, nail technicians have reported that the use of nail products often cause asthmatic attacks and other allergies such as allergic contact dermatitis especially due to methacrylate found in acrylic monomers and polymers (Kreiss *et al*., 2006; Raposo *et al.*, 2017; Gonçalo *et al.*, 2018; Lamplugh *et al.*, 2019). However, Le *et al.*, (2015) argued that allergies were due to acrylic monomers and not polymers although both products contain methacrylate.

For chronic effects, VOC emissions from nail products can also be categorised as carcinogenic, genotoxic, reproductive toxicants, teratogens and endocrine disruptors depending on their toxicological profile (Takkouche *et al.*, 2009; Kolena *et al.*, 2017; Chang *et al.*, 2018; Quiros-Alcala *et al.*, 2019).

Based on the lipophilic characteristics, VOCs have shown to have negative repercussions on the reproductive system such as a decrease in fertility and increase in spontaneous abortions among pregnant women (Bukowski, 2001; Laslo-Baker *et al.*, 2004; Ho *et al.*, 2007; Peretz *et al.*, 2009; Llop *et al.*, 2010; Attarchi *et al.*, 2012; Swenberg *et al.*, 2013; Nilsson *et al.*, 2015; Lamplugh *et al.*, 2019).

Studies were done in the nail salon industry, usually focused on formaldehyde, toluene, and dibutyl phthalate as VOCs emitted during the use of nail polish. These are often referred to as the toxic trio. Formaldehyde is a carcinogen that is known to cause leukemia and cancers of the paranasal sinuses and nasopharynx (Heaton *et al.*, 2019). Toluene is a known potent human teratogen that particularly hinders the development of the foetus in terms of delay in neuronal development and facial as well as ear anomalies (Bowen and Hannigan, 2006; Llop *et al.*, 2010; Moradi *et al.*, 2019). Other effects of toluene are genotoxic, involving induction of oxidative stress, DNA damage, and dysregulation in cellular antioxidant defense, which can possibly lead to carcinogenesis (Kim *et al.*, 2011; Quach *et al.*, 2015; Grešner *et al.*, 2016). Phthalates are endocrine disruptors linked to teratogenic effects on the male reproductive system (Duty *et al.*, 2005; Bustamante-Montes *et al.*, 2013; Quach *et al.*, 2015; Varshavsky *et al.*, 2020) and disruption of thyroid hormone levels in women and often leads to preterm birth (Huang *et al.*, 2009; Ferguson *et al*., 2013; Quach *et al.*, 2015). Acetone used as nail polish remover has been associated with disorders of the central nervous system as well as malfunction of the liver and kidneys (Ho *et al*., 2007). In summary, all the above-mentioned studies have shown a significant correlation between exposure to VOCs emitted during nail treatment activities and the development of adverse health effects amongst nail technicians.

1.2.5 Field-based exposure studies versus controlled laboratory exposure studies

Previous studies have assessed exposure to VOCs exposure within various nail salon environments as summarized in Table 1. The findings from those field-based studies (assessed through an area or personal sampling) highlighted VOCs as environmental concentrations and not dose estimates. In risk assessment, dose estimates refer to the approximate quantity of the chemical that enters the body of the receptor and not necessarily, what is available in the environment. Hence, Goldin *et al.*, (2014) suggested conducting more field-based studies characterizing full-shift exposure by measuring breathing zone concentration (personal sampling) for individual VOCs.

Table 1: Available studies on VOCs emission in nail salons

Field-based studies	
Author	Findings (exposure levels/concentrations)
(Lamplugh *et al.*, 2019)	Acetone (3.6-45ppm), ethyl acetate (0.090-1.4 ppm), n-butyl acetate (0- 0.67 ppm) and MMA (1 ppm)
(Pavilonis *et al.*, 2018)	Total VOC concentrations of 12 ppm and 67 ppm
(Goldin *et al.*, 2014)	Total VOC median concentration 4800 ppb
(Alaves *et al.*, 2013)	Formaldehyde exceeded NIOSH REL = 16 ppb
(Quach *et al.*, 2011)	Average concentration: ethyl acetate (530 ppb), toluene (150 ppb) and MMA

Based on **Table 1**, there is a clear indication of variations of measured VOCs between different nail salons. Such variations are due to differences in the type of nail products used as well as nail treatment processes performed, type of ventilation, study designs and sampling methods (Heaton *et al.*, 2019). In addition, those variations influence the amount of the VOCs available in the air, the dilution and removal rate of the contaminants.

To account for such variations, Heaton *et al.* (2019) conducted a controlled laboratory study to obtain true concentrations of VOCs emitted from nail salon products during the nail polish application process. Findings from the study by (Heaton *et al.*, 2019) showing that butyl acetate, ethyl acetate, and formaldehyde were ±330 ppm, ±440 ppm and ±0.22 ppm respectively. The results, therefore, showed there is no comparability between the field-based studies (illustrated in Table 1) and experimental studies due to the variations previously discussed. Also unclear was that VOC concentrations from a controlled laboratory environment somewhat exceeded the threshold limit values, whereas studies were done in an uncontrolled field environment reported concentrations either "below detection limit" or "within the threshold limit."

Researchers Park *et al.*, (2014) reported that in the informal sector, nail treatments are carried out in the same area as hair treatments. Thus, a controlled laboratory study will be significant in predicting exposure concentration levels emanating from nail treatments. This will enable the characterisation of field-based VOCs and their sources as well as accounting for variations resulting from potential confounders.

1.2.6 Differences between active/passive sampling and real-time monitoring of VOCs in nail salons

The traditional approach normally involves the use of absorbent material in the form of cartridges or badges to collect VOC samples and thereafter taken to the analytical laboratory for analysis. For example, a field-based study by Ceballos *et al.*, (2019) made use of passive thermal desorption tube-type samplers clipped to the breast pocket of the nail technician for personal monitoring while for area sampling the same sampler type was placed at a fixed point thereafter all samples taken to the laboratory for VOCs analysis. On the other hand, Heaton *et al.*,(2019) used passive vapour monitors to measure VOCs in the assumed breathing zone of the nail technician in a laboratory-controlled study. Apart from the traditional approach being time-consuming in terms of sampling, transportation of samples and intense technical analysis, Chen *et al.,* (2006) and Badjagbo *et al.*, (2007) argued that the traditional approach lacked critical scientific information on spatial and temporal variations of concentrations during sampling due to the use of gravimetric analysis.

Real-time monitoring is a modern approach that involves obtaining direct reading measurements without the hassle of taking the sample to the laboratory for further processing and analysis (Duarte *et al.*, 2014). Commonly used direct-reading instruments in monitoring VOCs related to nail products include the photoionization detector (PID), flame-ionisation detector (FID), and the infrared spectrophotometer (IR analyser). In particular, the PID operates by responding to the energy provided when the PID lamp absorbs the chemical, ionizing the electrons given off from the chemical. The PID is non-selective, has a fast response time, and is easy to use, however, it is subjected to inferences from water vapour or oxygen especially when using a high-energy lamp (Duarte *et al.*, 2014). Duarte *et al.*, (2014) highlighted that direct-reading instruments are far much better in aiding with highlighting activities and the related measurement levels.

Field-based studies by Goldin *et al.*, (2014) and Harrichandra *et al*., (2020) made use of the UltraRAE 3000 and ppbRAE (type of PIDs) respectively, to obtain area sampling results of

VOCs in different nail salons. Other studies conducted outside the scope of nail salons using a direct-reading instrument include assessing airborne exposures from cleaning tasks (Bello *et al.*, 2010) and assessing total volatile organic compound (TVOC) exposures associated with cleaning and disinfecting tasks in healthcare settings (Virji *et al.*, 2019). Contrary to all the exemplary studies provided, Tsigonia *et al.*, (2010) made use of both the traditional and modern approaches. Tsigonia *et al.*, (2010) collected samples using charcoal sorbent tubes with sampling pumps and fixed them per workstation for area sampling and used ppbRAE to measure short-term TVOCs.

1.3 Problem statement and knowledge gaps

Globally, nail salon environments are typically enclosed indoor areas. Additionally, VOC concentrations tend to be greater in enclosed spaces and exacerbated by limited ventilation and environmental factors i.e., air exchange rate, temperature, and humidity (Tsigonia *et al.*, 2010; Moradi *et al.*, 2019). Exposure to VOC emissions from nail products has been associated with respiratory, neurologic, reproductive, and cancer-related health effects (Quach *et al.*, 2011). Furthermore, studies indicated evidence of increased concentrations of biomarkers and correlated health effects amongst nail technicians regardless of measured low levels of VOCs which do not exceed any occupational threshold limits (Grešner *et al.*, 2017). This means that nail technicians are greatly vulnerable to negative health effects considering their increased exposure duration in such environments.

Several indoor air monitoring and epidemiological studies in nail salons have been conducted. Such studies have used gravimetric analysis to assess emissions (VOCs and particulate matter) and show a correlation with health outcomes experienced by nail technicians. Furthermore, most of the studies concluded by providing comparisons between environmental concentrations obtained and the occupational exposure limits. Nevertheless, VOCs monitoring in the nail salons and comparing with occupational exposure limits does not address the exposure-receptor interaction comprehensively (Roelofs and Do, 2012). Consequently, the use of environmental concentration as a benchmark for exposure has led to the underestimation of exposure, despite reported health effects among nail technicians. In addition, because environmental concentration is not representative of the dose thus, when used solely it lacks scientific weight, especially when recommending exposure control interventions. Therefore, there is a need to provide dose estimates and not merely environmental concentrations as a basis of exposure.

There is a need to shift from traditional gravimetric analysis to the use of real-time instrumentation to characterise exposure and further scrutinize the environmental concentration to provide dose estimates. Currently, there is only one international study (Heaton *et al.*, 2019) conducted in an experimental set-up to simulate nail salon activities to replicate a real-world scenario to characterise VOC concentration. Additionally, such a research gap has not been tapped into within the South African context especially using real-time instrumentation hence there is relatively no exposure data available on VOCs in nail salons.

1.4 Justification and rationale of the study

VOC exposure from nail product emissions has been associated with health effects ranging from skin sensitivity to more severe impacts such as allergic contact dermatitis regardless of the level of concentration and exposure duration. Additionally, studies have also shown a strong correlation between VOC exposure and biological effects such as increased risk to infertility and DNA mutations (Baste *et al*., 2008). The results from the current study will assist in characterisation of VOC exposure during nail treatment processes in a controlled environment. The results will further assist in identifying and understanding factors that may influence the transformation of VOCs under defined exposure scenarios. To make the data more beneficial in terms of including the exposure-receptor interaction, dose estimates will be determined. Such dose estimates will address the internal dose as taken in by the receptor and not merely concentration available in the environment, as reported in most of the nail salon-related literature. Overall, the study will be establishing a health risk assessment and not just VOC concentration compared to threshold limits.

The relevance of this study is that it builds onto the main study, which focuses on occupational exposure to chemicals and health outcomes amongst nail technicians, particularly in Johannesburg. The current study, therefore, provides emission concentration levels obtained in a controlled laboratory environment. Such concentration level data will be important for source apportionment during field-based studies especially since the informal sector salons conduct both hair and nail treatments in the same space.

Lastly, such South African personalized exposure data will inform better interventions to reduce exposure while accounting for variations, especially since the main study will be considering the efficiency of the current control measures/interventions in place.

1.5 Research Question

What are the exposure characteristics of VOCs emitted during nail treatments in a controlled laboratory environment?

1.6 Aim

The aim of the study was to characterise exposure to eight (8) selected VOCs emitted during the use of nail products, and to determine the relative health risk amongst nail technicians in a controlled laboratory environment.

1.7 Objectives

To achieve the above aim, the following objectives were set out:

a. To measure the concentrations of eight selected VOCs during nail treatment in a controlled laboratory environment.

b. To characterise and compare exposure to VOCs at multiple nail treatment activities.

c. To assess the efficacy of natural ventilation in controlling VOC emissions.

d. To assess the health risk of exposure to selected VOCs during the nail treatment process.

1.8 Scope of the study

The study was limited to the characterisation of VOC emissions during two distinct nail treatments namely acrylic as well as buff and paint in a controlled laboratory environment. The monitoring took place under a controlled laboratory environment in the absence of any persons except the principal investigator. Triplicates of each exposure scenario were monitored using a PID instrument. For each nail treatment, VOC emissions were measured when there was nail treatment without ventilation and nail treatment with ventilation. This data was further used to assess the effectiveness of natural ventilation on VOC emissions. Lastly, since the compounds of interest were non-carcinogenic, the hazard quotient was calculated to derive the health risk of each compound.

CHAPTER TWO- METHODOLOGY

This chapter gives a description of the methodology followed in this study. It indicates the description of the study area, experimental set-up, the instrument used, and the process of monitoring the VOCs. The chapter further outlines the analysis of the data obtained as well as the quality control measures implemented to ensure the reliability and validity of the data.

2.1 Methods and Materials

2.1.1 Description of the field-based nail salons

Prior to this study, the main PhD study in which this project was nested under conducted a pilot field-based study which comprised of a walkthrough of the nail salon and face-to-face interviews of nail salon employees. The PhD study encompassed a walkthrough of the nail salon to observe the size dimensions and layout of the salon as well as the work practices involving a variety of nail treatments. Additionally, questionnaires to further understand the work practices were administered.

2.1.2 Description of the study area and experimental sampling set-up

A controlled laboratory environment was used to simulate nail salon activities in the informal sector nail salon setting. The controlled laboratory setting comprised of a room with three windows, two doors, and a local extraction ventilation system in the form of a fume cupboard. The experimental set-up was arranged to mimic the field-based nail salon layout as shown in **Figure 1** and **Figure 2**.

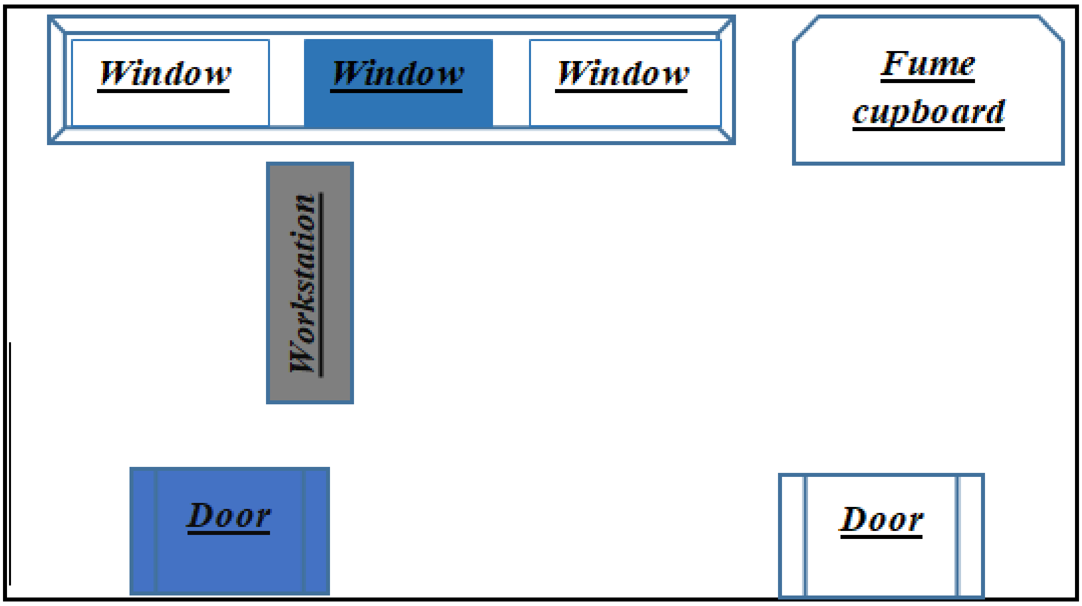

Figure 1: Schematic diagram of the laboratory mimicking a nail salon

Figure 2: Image taken of the experimental set-up in the laboratory

2.1.3 Field-based exposure data

From the main PhD study, the questionnaires were administered to 60 nail salon employees to obtain the demographic information, work shift patterns, types of nail treatments performed and the duration of each nail treatment, as well as the products used for each nail treatment. The safety data sheet was obtained to check the chemical composition of each of the products used for the nail treatments. All the information from the main PhD study informed the experimental set-up to mimicking the field-based scenario as well as the activities performed, VOCs of interest and exposure data.

2.1.4 VOC sampling instruments

For this current study, eight VOCs (ethyl alcohol, acetone, ethyl methacrylate, methyl methacrylate, butyl acetate, ethyl acetate, toluene and xylene) were monitored. Monitoring was done through the use of a MiniRAE 3000 Photoionization detector (PID) [Model PGM-7320; SN 592-926156 Version 2.16; Keison Products UK].

Prior to measuring, the instrument was calibrated internally through the following 2 steps of calibration (zero calibration using clean air assuming it was free from any contaminants) and secondly span calibration using the Isobutylene by connecting the cylinder to the PID probe by a telfon tube). The PID was set to log data, capture data, and average at 5 seconds intervals. To extract the data from the PID, a PID software was installed in the laptop, and the PID was connected to the laptop through a USB cable. Data were then exported from the PID based on the period monitored.

2.1.5 VOC monitoring location and activities undertaken

Monitoring of VOCs was conducted on two separate days and each day was dedicated to a particular distinct nail treatment (either acrylic or buff and paint). Furthermore, each nail treatment was divided into two defined exposure scenarios. The scenarios comprised of conducting the experiment without ventilation while the other scenario with ventilation in the form of a window and door open throughout the duration of the treatment. Monitoring of the nail treatment under the respective exposure scenario was conducted in triplicates. The PID was placed 25 cm from the workstation and elevated to 10 cm from the workstation as seen in **Figure 3.** Notably, the elevation was to ensure the 30 cm breathing circumference of the receptor regardless of the receptor’s height when seated.

Figure 3: PID set up in the workstation

The activities were undertaken in a controlled laboratory environment in the presence of only the principal investigator. A miniature practice hand was used to mimic the client and the nail treatment done on the miniature practice hand by the principal investigator (considered as the nail technician). Prior to and post monitoring of the treatment activity, background measurements were taken for 5 minutes. During acrylic nail treatment, the products were decanted into small containers for ease of dipping of the products. The miniature practice hand underwent nail preparation (sanitised and nails were filed to the desired shape and then sanitised again). Thus, pre-sanitising ensured the removal of all filed nail particles. Then, a brush was dipped into the monomer then pink polymer powder to create a paste mixture to apply on the nails. In between the application of the paste mixture, the brush was dipped into acetone to avoid the hardening of the brush bristles to make it easier to work with. The nails were then left to dry before filing to remove any bumps as well as smoothing and finishing of the nails for a glossy look. The decanted products were left open throughout the treatment duration. Overall, the treatment took 32 minutes excluding the 5-minutes background measurements.

The buff and paint treatment involved nail preparation (sanitising the miniature practice hand before filing the nails to the desired shape). After filing, acetone was drenched on the cotton pads in order to wipe the nails. Then nail polish was applied to the nails and coated four times on each nail. After waiting for the nail polish to dry, buffing and shining of the nails was done to provide a gloss finish. The buff and paint treatment lasted for 35 minutes excluding the 5-minutes background measurements.

Post each exposure scenario, the controlled laboratory environment was vented for an hour using three windows, a door as well as three fans (one located less than a meter from the workstation while the other two were placed at least 2 meters away from the workstation). Lastly, the use of exposure scenarios was to account for variability especially amongst nail salons where some will prefer no opening of a door and windows whereby others prefer windows and door opened. Again, seasonal variability especially in hot conditions often results in the door and window opened within the nail salons whereas, in cold conditions, the door and windows are often closed.

2.2 Data analysis

2.2.1 VOC concentration during nail treatments

Data exported from the PID was transferred to Microsoft Excel 2010. Then the data was cleaned by removing outliers. Averages of the nail treatments under the two exposure scenarios were calculated then multiplied by the correction factor of the mixture obtained using Equation 1 and results reported in mg/m^3.

$$CF = \frac{1}{\left(\frac{X1}{CF1}\right)+\left(\frac{X2}{CF2}\right)+\left(\frac{X3}{CF3}\right)+\cdots\left(\frac{Xi}{CFi}\right)} \qquad \text{Equation 1}$$

X- referred to the percentage of the chemical in the product ÷ 100 where CF is the correction factor of the chemical as obtained from the PID Technical Note (TN-106).

2.2.2 Statistical analysis

The student F-test and T-test were used to study the statistical significance of the TVOCs at each nail treatment under different exposure scenarios. Moreover, to calculate the concentration of the individual chemicals (eight selected VOCs), the average TVOC concentration (using scenario A where activities are performed without ventilation as the worst-case scenario) was multiplied by the percentage composition and divided by 100 as per Equation 2.

$$Concentration_{\ (chemical)} = Average\ TVOC\ x \frac{Composition\ (\%)}{100} \qquad \text{Equation 2}$$

The percentage composition (%) referred to the percentage of the chemical in the product which was indicated on the Safety Datasheet.

Lastly, the time-weighted averages were calculated using Equation 3 to provide the average TVOC concentration for the duration of the nail treatment. A single nail treatment involved sanitising of the miniature practice hand, filing and shaping of the nails, application of the monomer-polymer paste or the nail polish then waiting for the nails to dry before buffing and shining for a gloss finish.

$$TWA = \frac{(C1\ x\ T1)+(C2\ x\ T2)+(C3\ x\ T3)..+Cn\ x\ Tn}{T\ (total\ time)} \qquad \text{Equation 3}$$

Where:

TWA was the time-weighted average.

C was the concentration of the TVOC.

T was the time taken to complete a nail treatment activity.

2.2.3 Dose estimates for health risk assessment

Given that measuring of TVOCs provides the environmental concentration, the calculation of the dose estimates using the concentration of the selected eight VOCs provide the concentration of the exposure that is taken in by the receptor over a specified period.

a) Hazard Identification

   The selected eight VOCs were classified into carcinogenic or non-carcinogenic. Thereafter, the US EPA and South African statistics default values were used as input parameters in the health risk assessment process. The USEPA defaults values are shown in **Table 2**.

b) Exposure assessment

   The dose estimates were expressed as the chronic daily intake (mg/kg/day), and it was calculated using Equation 4. Thus, the concentrations from the PID were used for the exposure assessment. The parameters that were considered included environmental concentration, inhalation rate, duration of exposure, average body weight, and exposure frequency. It was important to note that **Table 2** illustrates the values used (default values from the US EPA mixed with those obtained from the pilot study conducted in the main PhD study).

Table 2: Summary of exposure parameters used in this study

Parameter	Description	Value	Unit
C	Room concentration	-	mg/m^3
IR	Inhalation rate	20	m^3/day
BW	Body weight	70 kg males/60 kg females	Kg

ED	Exposure days	117 (9-hour shift per day)	Days/ year
YE	Years of exposure	25 (Worker)	Years
AT	Years in lifetime	63 males/ 67 females	Years

The chronic daily intake (CDI) for both carcinogenic and non-carcinogenic VOCs was calculated using the following Equation 4

$$CDI\ (averaged\ daily\ intake) = \frac{C\ x\ CF\ x\ IR\ x\ ED}{BW\ x\ AT} \qquad \text{Equation 4}$$

Where:

CDI the chronic daily intake over a year (averaged) in mg/kg/day;
C the concentration in (mg/m^3) of the chemical of interest;
CF the concentration conversion factor (mg/µg = 0.001 or 1 µg);
IR the inhalation rate (default value for worker 20 m^3/day);
ED obtained using Equation 5;
BW the average body weight (60 kg for females and 70 kg for males);
AT the number of days per year (non-carcinogenic= ED).

$$\text{ED} = \frac{\text{Average exposure duration}}{\text{24 hour per day}}\ \text{X 117 days in a year} \qquad \text{Equation 5}$$

Where:

ED was the exposure duration (days/year);
Average exposure duration was the duration of the nail treatment (converted from minutes to hours);
9 hours was the averaged total hours worked by nail technicians per day;
117 days was the number of exposure days in a year.

In addition to the CDI $_{\text{(average daily intake)}}$, the cumulative lifetime exposure, a cumulative lifetime exposure concentration intake for 25years was calculated using Equation 6

$$CDI\ (25\ years\ dose) = \frac{\sum CDI\ x\ 250\ x\ YE}{67/63} \qquad \text{Equation 6}$$

Where:

CDI $_{\text{(25 years dose)}}$ the cumulative average 25-year dose in mg/kg;
CDI the chronic daily intake (mg/kg/day);

YE estimated lifetime occupational exposure duration equivalent to 25 years;

117 the total number of days in a year;

67 years- female/ 63 years male life expectancy in South Africa.

Moreover, an adjusted lifetime chronic daily intake (CDI_{adj}) was calculated as per the risk assessment accounting for life expectancy in for a South African female. The CDI_{adj} was calculated using the following Equation 7.

$$CDI\ adj = \frac{CDI\ (25\ years\ average\ dose)}{life\ expectency\ in\ days} \quad \text{Equation 7}$$

Where:

CDI adj was the lifetime chronic daily intake;

$CDI_{(25\ years\ dose)}$ was the cumulative average 25-year dose (mg/kg);

Life expectancy in days (67/63 years x 365 days per year).

Lastly to complete the health risk assessment the non-cancer risk was calculated using Equation 8:

$$HQ = \frac{CDI}{RfD}\ X\ \frac{IR}{BW} \quad \text{Equation 8}$$

Where:

HQ was the hazard quotient

$CDI_{(adj)}$ the cumulative average 25-year dose (mg/kg);

RfD was reference dose (mg/kg/day) obtained from the US EPA guideline (see **Table 3**);

IR referred to the inhalation rate (20 m^3- US EPA default value);

BW referred to the body weight (70 kg for males and 60 kg for females);

HQ < 1 meant that low probability of developing a health outcome;

HQ > 1 high probability of developing adverse health outcome.

Table 3: Reference concentrations as per US EPA guidelines

Chemical	Reference dose (R*f*D) (mg/kg/day)
Acetone	0.9
Toluene	0.08
Xylene	0.2
Methyl methacrylate	1
Ethyl acetate	0.9

2.3 Quality control

The PID instrument was calibrated by a SANAS accredited laboratory. Additionally, onsite calibration was conducted according to requirements stipulated by the manufacturer. Before monitoring began, two steps calibration was done in the following sequence, firstly zero calibration using clean air (assuming it was free from any contaminants) and ran for 30-seconds. Once the first step was completed, the PID moved to the second step which was the span calibration which used Isobutylene as a reference gas. This involved connecting the cylinder with the reference gas to the PID probe by means of a Teflon tube and ran it for 30-seconds. Once the calibration was completed, the PID indicated the 100 ppm concentration equivalent to the concentration of the reference gas. The instrument was left to ran for 30 minutes before monitoring was done.

CHAPTER THREE- RESULTS

This chapter outlines the results of each objective of the study. It indicates the findings of the field-based pilot study as well as the scenario-based TVOC and VOC emissions from two nail treatments under a controlled laboratory environment. It further highlighted dose estimates obtained through the VOC emissions data together with exposure data.

3.1 Field-based exposure data

From the field-based pilot study conducted in the main PhD study, the exposure data based on the informal nail salons were made up of both males and females as illustrated in **Table 2**. Furthermore, the employees worked 9-hour shift per day for 6 days a week. There were various nail treatments conducted such as acrylic, gelish as well as buff and paint. However, for this study, only two nail treatments were adopted as observed in the field-based pilot study namely, acrylic as well as buff and paint. Each of the nail treatments lasted on average ±35 minutes. The nail technicians performed on average seven treatments in a 9-hour daily shift. The nail treatments product inventory comprised of a sanitiser, acetone, nail polish, monomer, and polymer as found in the main PhD study.

3.2 TVOC concentration under exposure scenarios in a controlled laboratory environment

Figure 4 show TVOCs emitted during a single acrylic as well as buff and paint nail treatment under two exposure scenarios. Furthermore, Figure 4 indicated that without ventilation the average TVOC for acrylic treatment was 605 mg/m^3. However, with the introduction of ventilation by window opening and door opening, the TVOC decreased to 302 mg/m^3. A similar observation was made during buff and paint treatment whereby without ventilation the TVOC was 305 mg/m^3 but with ventilation through an open window and door, the TVOC decreased to 82 mg/m^3. In addition, the figure clearly shows that the acrylic nail treatment had much higher average TVOC concentrations compared to the buff and paint nail treatment.

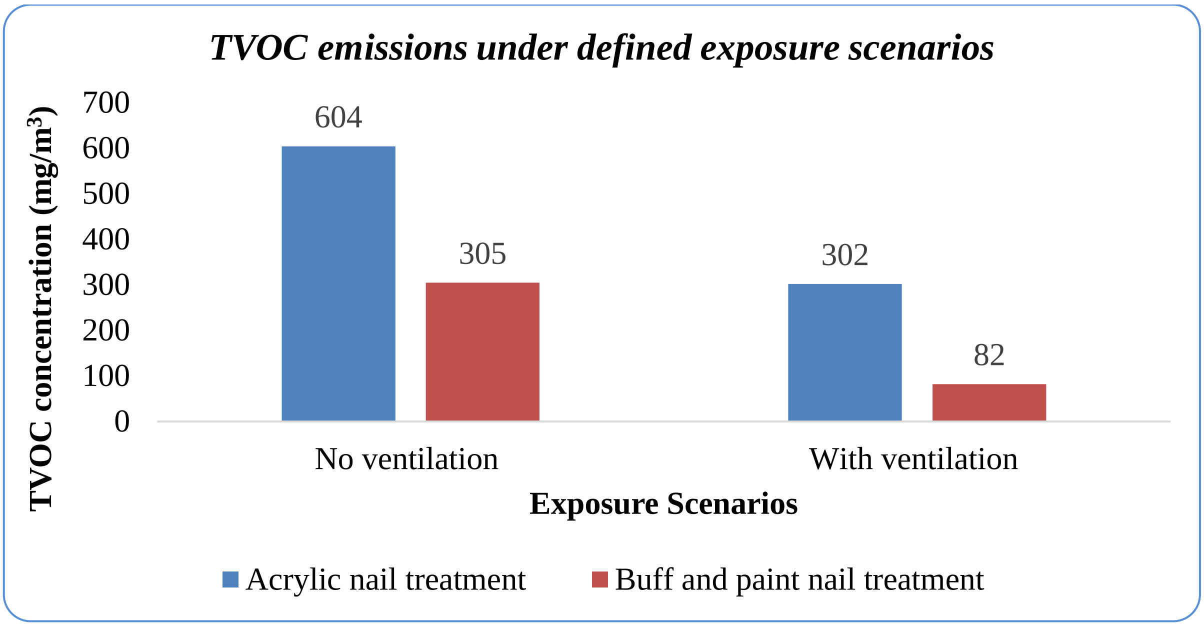

Figure 4: Averaged TVOC under defined exposure scenarios

Additionally, this showed that with ventilation through an opened window and door there was a 50% and more reduction of the TVOC concentration during both nail treatments as seen in **Table 4** and **Table 5**.

Table 4: TVOC concentrations under defined exposure scenarios during a single acrylic nail treatment

Exposure Scenario	**Concentration (mg/m^3)**	**STDev N=3**	**Statistical analysis**			
			%difference	**F-test**	**T-test**	**Sig @95**
Nail treatment without ventilation vs.	604	3,4	50.1%	0,90	<0.001	Yes
Nail treatment with ventilation	302	3,0				

Table 5: TVOC concentrations under defined exposure scenarios during a single buff and paint nail treatment

Exposure Scenario	Concentration (mg/m^3)	STDev N=3	Statistical analysis			
			%difference	F-test	T-test	Sig @95
Nail treatment without ventilation	305	7,1	73.0 %	0,48	<0.001	Yes
vs.						
Nail treatment with ventilation	82	3,99				

3.3 Concentration of eight selected chemicals found in nail products

As shown in **Table 6**, methyl methacrylate had the highest concentration of 598,2 mg/m^3 which was found in the monomer used during acrylic nail treatment. For buff and paint nail treatment, the concentrations of the majority of the VOCs were lower compared to the acrylic nail treatment. For instance, the concentration of butyl acetate, toluene, xylene and ethyl acetate were 76,2 mg/m^3, 51,8 mg/m^3, 15,2 mg/m^3 and 152,3 mg/m^3 respectively.

Table 6: Concentrations of the eight selected VOCs based on an acrylic as well as buff and paint single nail treatment

Chemicals of interest	Concentration (mg/m^3)
Ethyl alcohol	435,1
Acetone	301,6
Ethyl methacrylate	453,2
Methyl methacrylate	598,2
Butyl acetate	76,2
Toluene	51,8
Xylene	15,2
Ethyl acetate	152.3

Additionally, for exposure determination considering those nail technicians performed on average 7 treatments per day, the TVOC exposure concentrations were found to be 3237,7 mg/m^3 for acrylic nail treatment and 2518,9 mg/m^3 for buff and paint nail treatment. Based on the above findings, it was evident that acrylic nail treatment showed a higher TVOC exposure concentration, while the buff and paint TVOC concentration was roughly 1.5 times less than that of the acrylic nail treatment. However, it was important to note that a higher concentration does not always constitute a high-risk exposure scenario.

3.4 TVOC concentrations at various nail treatment processes

Figure 5 clearly illustrates that without ventilation the acrylic nail treatment process resulted in 67% of TVOC emissions and the emissions decreased to 33% with the introduction of ventilation.

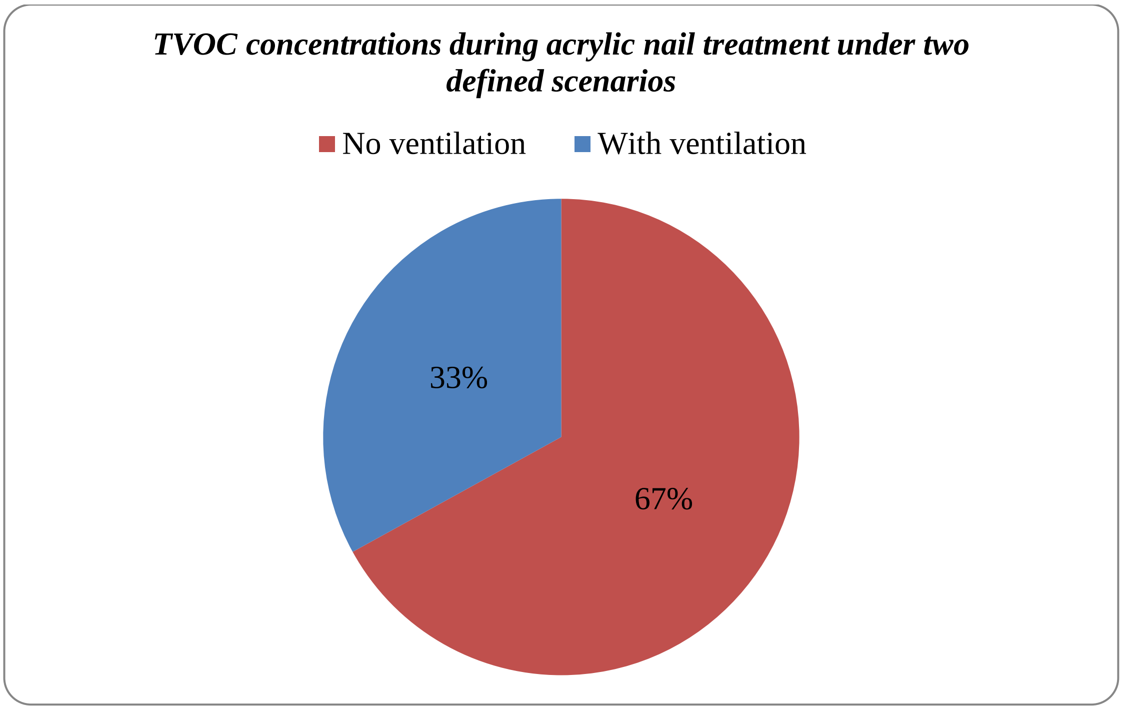

Figure 5: TVOC concentration during acrylic nail treatment

For buff and paint (**Figure 6**), the TVOC emissions were 79% without ventilation and decreased to 21% with the introduction of ventilation. Notably, the introduction of ventilation resulted in a reduction of TVOC available in the receptor's microenvironment in both nail treatments.

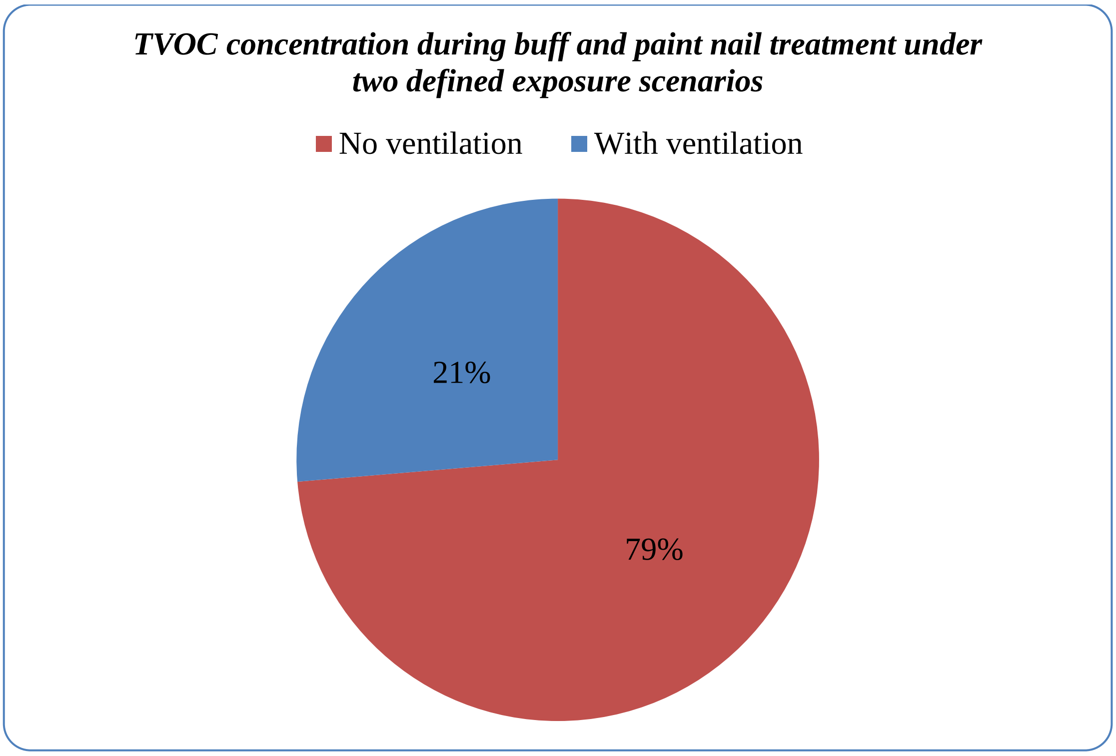

Figure 6: TVOC concentration during buff and paint nail treatment

In **Figure 7**, there was an increase of approximately ±701 mg/m^3 and ±402 mg/m^3 in 7.5 minutes during nail treatment without ventilation and during nail treatment with ventilation, respectively. This was due to the decanting of the acetone, monomer, and polymer into smaller containers. Thereafter spraying of sanitiser onto the miniature practice hand resulted in a further emission into the environment and the peak was reached when applying the monomer-polymer paste between 10 minutes and 15 minutes. The peaks were 2322 mg/m^3 and 2373 mg/m^3 without ventilation but reduced to 1941,9 mg/m^3. As the acrylic nails were left to dry, there was a sharp decrease from 17.5 minutes to 20 minutes until the concentration reached an equilibrium state during the nail shine.

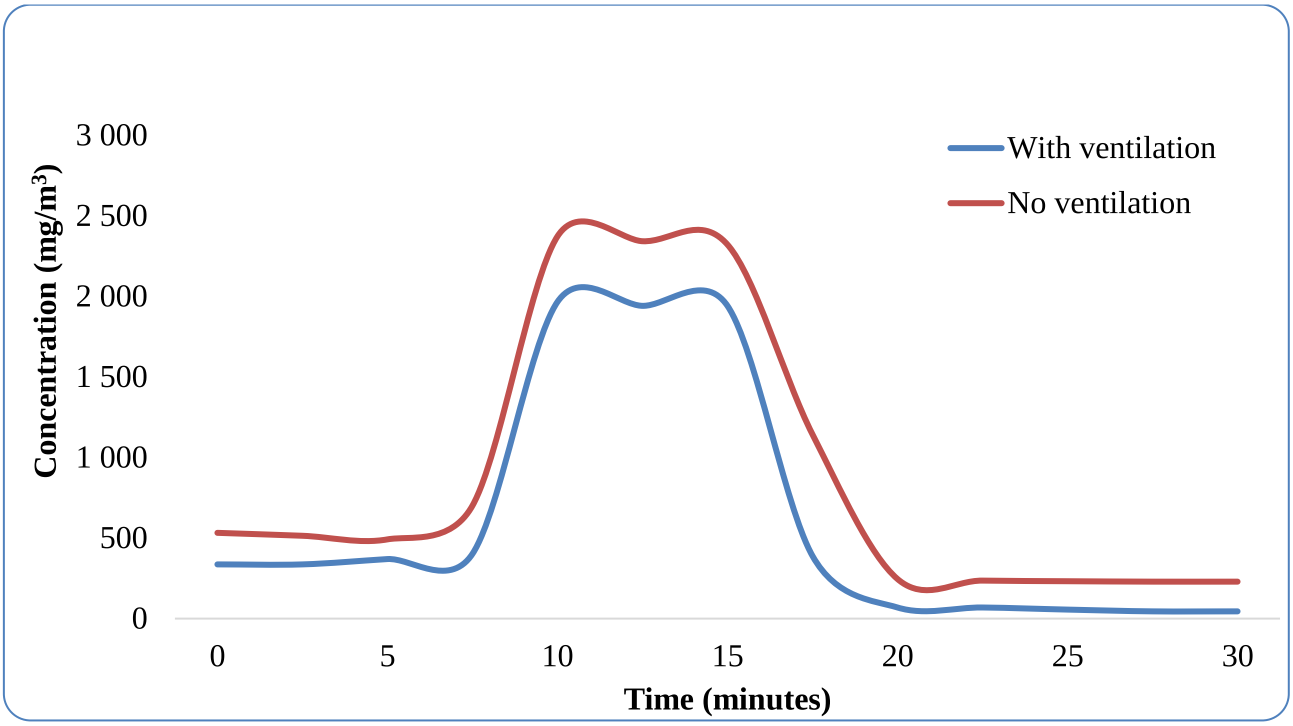

Figure 7: Time series plot during acrylic nail treatment under two exposure scenarios

Figure 8 showed the TVOC increase of approximately ±175,7 mg/m^3 and ±35,2 mg/m^3 at 5 minutes when there was nail treatment without ventilation and nail treatment with ventilation, respectively. This was due to the spraying of the sanitiser on the miniature practice hand. During nail polish application, the peak was reached between 10 minutes and 16.23 minutes. The peaks were 1778,1 mg/m^3 and 1820,6 mg/m^3 without ventilation but reduced to 1420,3 mg/m^3 and 1496,8 mg/m^3. As the nail polish was left to dry, there was a sharp decrease from 17.5 minutes to 22,5 minutes until the concentration reached an equilibrium state during nail buffing which was the final step of the nail treatment.

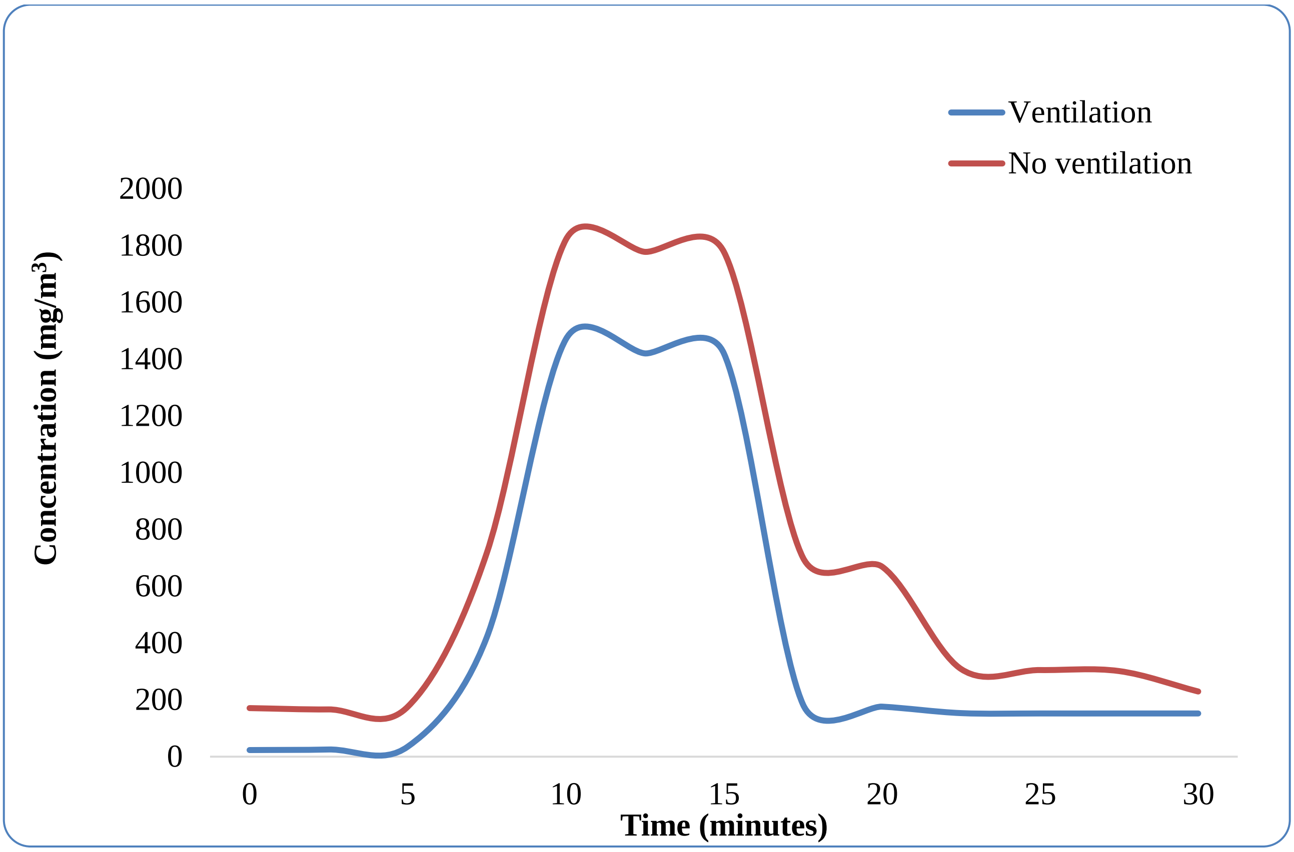

Figure 8: Time series plot during buff and paint nail treatment under two exposure scenarios

In **Table 7**, there was statistical significance ($p<0.05$) in all activities during acrylic nail treatment without ventilation except during decanting and nail preparation ($p>0.05$). Due to the absence of ventilation and lack of dilution, VOCs emitted during each activity tend to accumulate in the environment.

Table 7: TVOC concentration during acrylic nail treatment without ventilation

Activity	Concentration (mg/m^3)	STDev N=3	Statistical analysis			
			%difference	F-test	T-test	Sig @95
Decanting vs. Nail preparation	532,47 499,38	0,40 12,85	6,1%	<0,001	0,0468	No
Nail preparation vs. Paste application	499,38 2355,10	12,85 15,75	78,8%	0,799	<0,001	Yes
Paste application vs. Nail drying	2355,10 1129,76	15,75 12,17	60,2%	0,748	<0,001	Yes
Nail drying vs. Nail finishing	1129,76 235,87	12,17 8,78	79,1%	0,685	<0,001	Yes
Decanting vs. Paste application	532,47 2355,10	0,40 15,75	72,4%	<0,001	<0,001	Yes
Nail preparation vs. Nail drying	499,38 1129,76	12,85 12,17	55,8%	0,946	<0,001	Yes
Decanting vs. Nail drying	532,47 1129,76	0,40 12,17	63,5%	<0,001	<0,001	Yes
Paste application vs. Nail finishing	2355,10 235,87	15,75 8,78	89,9%	0,474	<0,001	Yes
Nail preparation vs. Nail finishing	499,38 235,87	12,85 8,78	52,8%	0,638	<0,001	Yes
Decanting vs. Nail finishing	532,47 235,87	0,40 8,78	55,7%	<0,001	<0,001	Yes

Table 8 outlines TVOC concentration during acrylic nail treatment with ventilation. The table shows during acrylic nail treatment when there was ventilation, there was statistical significance ($p<0.05$) during nail drying and nail finishing. This result was expected as a wet surface tends to emit more VOCs compared to a dry surface. Moreover, in comparison to when there was no ventilation, it was unexpected that decanting and nail drying showed no statistical significance ($p>0.05$).

Table 8: TVOC concentration during acrylic nail treatment with ventilation

Activity	Concentration (mg/m^3)	STDev N=3	Statistical analysis			
			%difference	F-test	T-test	Sig @95
Decanting vs. Nail preparation	347,63 701,24	19,07 0,000029	50,4%	<0,001	<0,001	Yes
Nail preparation vs. Paste application	701,24 1950,09	0,000029 14,17	64,0%	<0,001	<0,001	Yes
Paste application vs. Nail drying	1950,09 389,20	14,17 0,03	80,0%	<0,001	<0,001	Yes
Nail drying vs. Nail finishing	389,20 55,99	0,03 13,06	85,6%	0,635	0,010	Yes
Decanting vs. Paste application	347,63 1950,09	19,07 14,17	82,2%	0,711	<0,001	Yes
Nail preparation vs. Nail drying	701,24 389,20	0,000029 0,03	44,5%	<0,001	<0,001	Yes
Decanting vs. Nail drying	347,63 389,20	19,07 0,03	10,7%	<0,001	0,064	No
Paste application vs. Nail finishing	1950,09 55,99	14,17 13,06	97,1%	0,918	<0,001	Yes
Nail preparation vs. Nail finishing	701,24 55,99	0,000029 13,06	92,0%	<0,001	<0,001	Yes
Decanting vs. Nail finishing	347,63 55,99	19,07 13,06	57,5%	0,638	<0,001	Yes

Table 9 outlines the TVOC concentration during buff and paint nail treatment with ventilation. The table shows that during buff and paint nail treatment when there was ventilation, there was no statistical significance ($p<0.05$) between nail drying and nail buffing. This result was not expected as a wet surface tends to emit more vapours than a dry surface especially since the nails are still relatively wet.

Table 9: TVOC concentration during buff and paint nail treatment with ventilation

Activity	Concentration (mg/m^3)	STDev N=3	Statistical analysis			
			%difference	F-test	T-test	Sig @95
Nail preparation vs. Wiping nails with acetone	27,90 420,03	6,38 0	93,4%	<0,001	<0,001	Yes
Wiping nails with acetone vs. Nail polish application	420,03 1736,84	0 28,51	75,8%	<0,001	<0,001	Yes
Nail polish application vs. Nail drying	1736,84 162,80	28,51 18,47	90,6%	0,592	<0,001	Yes
Nail drying vs. Nail buffing	162,80 153,11	18,47 23,23	5,9%	0,775	0,300	No
Nail preparation vs. Nail polish application	27,90 1736,84	6,38 28,51	98,4%	0,095	<0,001	Yes
Wiping nails with acetone vs. Nail drying	420,03 162,80	0 18,47	61,2%	<0,001	<0,001	Yes
Nail preparation vs. Nail drying	27,90 162,80	6,38 18,47	82,9%	0,213	<0,001	Yes
Nail polish application vs. Nail buffing	1736,84 153,11	28,51 23,23	91,2%	0,798	<0,001	Yes
Viping of nails with acetone vs. Nail buffing	420,03 153,11	0 23,23	63,6%	<0,001	0,002	Yes
Nail preparation vs. Nail buffing	27,90 153,11	6,38 23,23	81,9%	0,140	<0,001	Yes

Table 10 outlines the TVOC concentration during buff and paint nail treatment without ventilation. Additionally, there was no statistical significance ($p<0.05$) during wiping nails with acetone and nail drying.

Table 10: TVOC concentration during buff and paint nail treatment without ventilation

Activity	**Concentration (mg/m^3)**	**STDev N=3**	**Statistical analysis**			
			%difference	**F-test**	**T-test**	**Sig @95**
Nail preparation vs. Wiping nails with acetone	171,03 690,93	4,63 25,99	75,3%	0,062	<0,001	Yes
Wiping nails with acetone vs. Nail polish application	690,93 1792,29	25,99 24,51	61,5%	0,941	<0,001	Yes
Nail polish application vs. Nail drying	1792,29 679,96	24,51 18,27	62,1%	0,715	<0,001	Yes
Nail drying vs. Nail buffing	679,96 305,13	18,27 3,65	55,1%	0,077	<0,001	Yes
Nail preparation vs. Nail polish application	171,03 1792,29	4,63 24,51	90,5%	0,069	<0,001	Yes
Wiping nails with acetone vs. Nail drying	690,93 679,96	25,99 18,27	1,6%	0,661	0,291	No
Nail preparation vs. Nail drying	171,03 679,96	4,63 18,27	76,9%	0,121	<0,001	Yes
Nail polish application vs. Nail buffing	1792,29 305,13	24,51 3,65	82,9%	0,043	<0,001	Yes
Wiping of nails with acetone vs. Nail buffing	690,93 305,13	25,99 3,65	55,8%	0,039	<0,001	Yes
Nail preparation vs. Nail buffing	171,03 305,13	4,63 3,65	43,95%	0,766	<0,001	Yes

In **Table 7-10** the statistical analysis during nail treatment activities for both acrylic as well as buff and paint monitored under two defined exposure scenarios are shown. It was expected that the application of monomer-polymer paste and nail polish would be higher than decanting of products, nail preparation, nail drying, nail finishing, wiping nails with acetone, and nail buffing.

3.5 Occupational health risk evaluation

A) Exposure assessment

In this current study, field-based data obtained through the pilot study conducted in the main PhD study was essential for the determination of an ideal real-world exposure scenario. From the field-based data, the information on the informal nail salon layout, types of nail treatments, conducting the nail treatments, inventory of products used for the different nail treatments, and local environmental conditions inclusive of ventilation options were recorded. Using the field-based data from the pilot study together with the controlled laboratory environment 9-hour daily TVOC emissions, the 9-hour daily shift estimated exposure concentration of the eight selected VOCs was obtained as illustrated in Table 11.

Table 11: 9-hour daily estimated exposure concentration

VOC	9-hour exposure concentration (mg/m^3)
Ethyl alcohol	3045,5
Acetone	2111,3
Ethyl methacrylate	3172,4
Methyl methacrylate	4187,5
Butyl acetate	533,2
Toluene	362,5
Xylene	106,6
Ethyl acetate	1066,4

B) Risk characterisation

Risk characterisation was derived firstly through the determination of the risk category as carcinogenic or non-carcinogenic for the eight selected VOCs. Toxicological data on the eight selected VOCs in this study were found to be non-carcinogenic. However, only five of the eight selected VOCs were considered for the risk characterisation because the other three did not have reference concentrations as per the US EPA guidelines. The risk characterisation process was completed by using a hazard quotient as a determinant for a risk score. The inherent non-carcinogenic risk was considered a probability to develop health effects when the HQ was above 1.

In **Table 12**, chemicals namely toluene, methyl methacrylate, acetone, and ethyl acetate showed the risk of developing health effects. Toluene had a high HQ of 8,9 whereby the xylene had the lowest HQ of 1,1.

Table 12: Non-carcinogenic risk for female nail technicians

Chemical	CDI (average daily dose) mg/kg/day	$CDI_{25\ year}$ mg/kg/day	$CDI_{adj.}$ mg/kg/day	HQ
Acetone	1015,2	443187	18,1	6,7
Toluene	120,8	52756,2	2,3	8,9
Xylene	35,5	15514,1	0,6	1,1
Methyl methacrylate	1395,9	609380,8	24,9	8,3
Ethyl acetate	355,5	155182,2	6,4	2,4

Like **Table 12**, it is shown in **Table 13** that toluene, methyl methacrylate, acetone, and ethyl acetate showed the risk of developing health effects. But xylene (HQ = 0,9) there was no probability of developing health effects amongst male nail technicians despite similar exposure to that of female nail technicians.

Table 13: Non-carcinogenic risk for male nail technicians

Chemical	CDI (average daily dose) mg/kg/day	$CDI_{25\ year}$ mg/kg/day	$CDI_{adj.}$ mg/kg/day	HQ
Acetone	870,1	403993,6	17,6	5,6
Toluene	103,6	48090,7	2,1	7,5
Xylene	30,5	14142,1	0,6	0,9
Methyl methacrylate	1196,4	555490	24,2	6,9
Ethyl acetate	304,7	141458,6	6,2	1,9

CHAPTER FOUR-DISCUSSION

In this chapter, the results are discussed in relation to the currently available literature. It highlights the correlations and contradictions of the results and current literature based on field-based exposure data, VOC concentrations during nail treatments and their activities under a controlled laboratory environment. Lastly, to close the chapter, the limitations and strengths of the study are explained.

4.1 Field-based studies exposure data

Lamplugh *et al.*, (2019), found that the nail salon industry comprised of females and males with body weights of 60,75 kg and 73,20 kg, respectively. Considering the South African context, the pilot study conducted in the main PhD study found those nail technicians comprised of both sexes, with body weights as 60 kg and 70 kg for females and males, respectively. Again, from the pilot study, nail technicians were found to work an average of 9-hours per week for 6 days per week, which is a similar finding to a study by Lamplugh *et al.*, (2019). In another study by Shendell *et al.*, (2018), nail technicians worked 10-hours per day for 5 days a week.

4.2 TVOC concentration under different exposure scenarios in a controlled laboratory environment

Previous field-based studies showed that acrylic nail treatment had a higher TVOC compared to other types of nail treatments provided therefore placing nail technicians at a much greater risk of chemical exposure (Quach *et al.*, 2018). Quach *et al.*, (2018) explained that the increased TVOC concentration of the acrylic nail treatment was based on the demand of the client as this type of nail treatment was cost-effective as it lasts longer than the buff and paint nail treatment.

Nail treatments performed in the presence of ventilation showed a 50% or more TVOC emissions s reduction and this was a similar finding to that reported in numerous literature. Additionally, nail salons that had either window(s) opened and/or door(s) opened showed a lower TVOC concentrations distribution (Goldin *et al.*, 2014), which was also evident in the current study when the nail treatments were performed with one window and door opened. This is because ventilation (either natural or mechanical) ensures air exchange which facilitates the dilution of the TVOC concentrations emitted (De Gennaro *et al.*, 2014; Goldin *et al.*, 2014; Caron *et al.*, 2020). On the other hand, absence or inadequate ventilation showed an increase in the TVOC concentrations in indoor settings (Shang *et al.*, 2016; Caron *et al.*, 2020).

There are different proxies used in accounting for the reduction of emissions (Hadei *et al.*, 2018). For example, in this study, the increase and the decrease in the TVOCs concentration were used as a proxy to observe the difference during nail treatment without ventilation and during nail treatment with ventilation. A study by Goldin *et al.*, (2014) made use of carbon dioxide as a proxy for ventilation. It has been highlighted in previous studies that the TVOC concentrations were consistent throughout the nail salons therefore, indicating that exposure may not be restricted to the workstation of the nail technician only (Goldin *et al.*, 2014).

Overall, results from this study evidently show that simple administrative control of the opening of window(s) and door(s) was a necessity in the reduction of exposure. This was also considerate of the economical feasibility of the nail salons in the informal sector as well as the infrastructural feasibility as in most informal sector infrastructural modifications and mechanical ventilation can be difficult to implement. Moreover, other studies highlighted the pros and cons of using mechanical ventilation in the nail salon setting. For example, researchers (Park *et al*., 2014; Tran *et al.*, 2020) reported that the presence of general exhaust ventilation tends to increase the VOC concentration up to 2.5 times. This is often observed with a ceiling exhaust duct as it tends to re-circulate the chemicals into the receptors' breathing zone therefore the local exhaust ventilation was stated to be more efficient (Park *et al*., 2014). In contrast, Harrichandra *et al*.,(2020) argued that general exhaust ventilation was effective in the reduction of TVOC exposure in nail salons. Additionally, the installation of an LEV system would capture and remove the contaminants from the receptors' microenvironment (Harrichandra *et al*., 2020).

4.3 Concentration of eight selected chemicals found in nail products

It has been highlighted that ethyl methacrylate was a safer alternative to methyl methacrylate. Additionally, it was observed that methyl methacrylate emitted during acrylic nail treatment was higher than that of ethyl methacrylate and this was consistent with the findings by (Quach *et al.*, 2011; Alaves *et al.*, 2013; Garcia *et al.*, 2015; Zhong *et al*., 2019). Noteworthy was that despite the introduction of ethyl methacrylate and the banning of methyl methacrylate by the US Food and Drug Administration (FDA) and other international states (Alaves *et al.*, 2013), it was still unregulated in nail products used in the South African informal sector nail salons. This resulted in the detection of the methyl methacrylate in the TVOC concentration, which was attributed to the lack of regulation regarding chemicals used in the nail salon industry particularly in the informal sector.

Like this study, Heaton *et al.*, (2019) simulated the nail polish application process in the laboratory and measured the VOCs emitted. Ethyl acetate had the highest concentration of 563 ppm, followed by butyl acetate, n-propyl acetate, isopropyl alcohol, isopropyl acetate, 1-butyl alcohol, ethyl alcohol and acetone with 444,09 ppm, 122,90 ppm, 99,7 ppm, 28,34 ppm, 22,32 ppm, 14,66 ppm, and 8,07 ppm respectively (Heaton *et al.*, 2019). In the current study, an almost identical pattern observed whereby ethyl acetate and butyl acetate had 152,34 mg/m^3, and 76,17 mg/m^3, respectively. However, the findings in the study by Heaton *et al.*, (2019) showed eight or more times the concentration of TVOCs compared to the current study. The increased variations between the two studies might be due to the difference in the methods used as one used passive and active sampling while the other used real-time monitoring. Another aspect reported was the possibility of cross-contamination as the experiment was in a shared laboratory (Heaton *et al.*, 2019), while in this current study the laboratory was sorely used to conduct this experiment.

Moreover, Tran *et al.*, (2020) reported ethanol, acetone, toluene, methyl methacrylate, butyl acetate and xylene as 530 ppm, 85 ppm, 13 ppm, 40 ppm, 100 ppm, and 23 ppm respectively from field-based studies. While Ma *et al.*, (2019) found that the concentration of acetone, methyl methacrylate and toluene were 58,47 ppm, 941,25 ppm, and 0,24 ppm respectively. From the above-mentioned findings and those of the current study, it was clear that methyl methacrylate emissions were the most dominant in the nail salon setting. Kopelovich *et al.*, (2015) conducted a study using two models (two-zone model and the well-mixed room model) to estimate toluene and found that the concentrations were 0.09 ppm, and 0.19 ppm respectively. As previously reported in this current study, sufficient ventilation aids with the reduction of the VOCs emissions and this was a similar finding in the study by (Kopelovich *et al.*, 2015).Tran *et al.*, (2020) stated that exposure was directly proportional to the number of clients served by a nail technician. This was also evident in the current study as TVOC emissions were higher for an averaged of 7 nail treatments than for a single nail treatment.

Chemicals in nail polishes, e.g., toluene have been associated with the central nervous system and reproductive-related health effects (Quach *et al.*, 2018). Whereas various literature studies have shown that methacrylates are generally allergens resulting in allergic contact dermatitis (DeKoven *et al*., 2017; Quach *et al.*, 2018). Previous studies have shown that even at low concentrations, methacrylates caused acute irritation of the skin, eyes, and respiratory tract as well as long-term skin sensitization and nervous system disorders (Henriks-Eckerman and Korva, 2012; Munguia *et al.*, 2016; Ceballos *et al.*, 2019). In this instance, concentration does not translate to the toxicity of the chemical, the risk the chemical possesses, and the health outcome thereof.

4.4 TVOC concentration at various nail treatment processes

With consideration of the time-series plots, numerous studies have reported the use of predictive models in estimating VOCs emission for the different sources (Xiong *et al.*, 2009; Yan *et al*., 2009; Chang *et al.*, 2018). During acrylic nail treatment, the products such as acetone, monomer, and polymer remained opened throughout the treatment and this might have had an impact on the increased TVOC emissions in the microenvironment of the receptor. Ceballos *et al.*, (2019) indicated that in the presence of airflow, evapouration of the monomer increased as the products remained opened. Hence, simply closing the products when not in use significantly decreases the TVOC emissions available in the microenvironment of the receptor (Tsigonia *et al.*, 2010).

According to Chang *et al.*, (2011) VOC emissions are categorised into three phases namely product remained wet after application, changing of the emissions from evaporative phase to diffusion phase, and the decrease of the emission rates as the surface is dry. The first phase occurred when the product was applied and remained wet. This phase was during the spraying of the sanitizer onto the miniature practice hand, the wiping off nails with acetone as well as application of the monomer-polymer paste or the nail polish. The wet surface of the miniature practice hand after sanitising, wiping off the nails as well as the application of the acrylic paste and nail polish tends to have an increased evapourative rate. There was evidence of statistical significance in terms of the wet and dry activities. Therefore, it can be argued that wet surfaces tend to emit more VOC compared to dry surfaces. Also, most chemicals increase evapouration rate at room temperature such as in the case of acetone. Moreover, despite the labelling on the monomer stipulated as odourless during the activities, a distinctive odour from the monomer was picked up and that raised some questions on what was meant with reference to the odourless assumption.

The VOC emissions rates in the first phase were reported to be high but tend to decay quicker (Chang *et al.*, 2011) which was also evident in this study. Secondly, the drying of the nails after the application of the nail product, Chang *et al.*, (2011) explained that in this second phase the emissions changed from the evaporative phase to a diffusion phase. This means that the VOC evaporated from the nail surfaces and diffused into the microenvironment air. Lastly, when the filing, buffing and shining of nails occurred, the nail surface was relatively dry thus VOC rate decreased, and the process lasted for a longer period. To sum up, the VOC concentrations decreased over time as seen in **Figure 7** and **Figure 8** illustrates the changes in the VOCs emitted concentration over time. Furthermore, Chang *et al.*, (2011) concluded that the decrease in the VOC concentration was due to the exponential decay because of the decrease in the VOCs emitted through evapouration.

Additionally, according to Pavilonis *et al*., (2018), the temporal trends of TVOC concentrations similar to the time-series plot illustrations (**Figure 7** and **Figure 8**) may suggest that time-weighted average sampling tends to underestimate the peak concentrations. Therefore, understanding the temporal trends means that the data will be sufficient in making informed decisions on the exposure of the nail technicians as well as the mitigation strategies in place.

4.5 Dose estimates of VOC during nail treatment processes

The CDI_{adj} of the chemicals in this study were higher for the female nail technicians compared to male nail technicians. Consistently, the findings from the study by Lamplugh *et al.*, (2019) highlighted that CDI was influenced by body weight and low averaged body weight led to high dose estimates. Thus, in the instance of xylene, it was noted that female nail technician was at risk of developing health effects compared to their male counterparts, especially since the average body weight was low for females. In the current study an inhalation rate default value for an average human was used, however (Lamplugh *et al.*, 2019) argued that differences in the inhalation rates between males and females often yields higher dose estimates for males compared to females especially for carcinogenic risk. Although this study focused on non-carcinogenic VOCs, a standardized inhalation rate for both sexes might have been the reason for the lower hazard quotient differences.

The hazard quotient for toluene and xylene were reported to be 1.60×10^{-4} and 1.54×10^{-2} respectively (Hadei *et al.*, 2018). Therefore, in the current study, the hazard ratio for toluene was more than twelve times and xylene was more than three times compare to the findings in the study by (Hadei *et al.*, 2018). A study by Baghani *et al.*, (2018) concluded that the non-carcinogenic risk for toluene was less than one, whereas for xylene there was a high possibility of developing an adverse health outcome (HQ> 1). The current study found the risk associated with xylene to be different between sexes due to a difference in body weight which is one of the exposure data parameters. Moreover, Moradi *et al.*, (2019) stated that despite the none significance of the non-cancer risk, employees in the nail salons reported symptoms such as irritation of the eyes, throat and also menstrual disorders. This meant that despite the negligible non-cancer risk by the chemicals as shown in **Table 11**, there might be a possibility that the use of the US EPA data might one way or another influence the output data applicable to the South

African context.

4.6 Limitations of the study

The size and layout of the laboratory will not be equivalent to that of field nail salons. To overcome the limitation, the experiment was in one portion of the laboratory following the size dimensions and layout of the field-based nail salon. However, the variation in terms of distribution of VOC concentration was noted.

The second limitation was possible leakages because of the opening under the doors and seals in the windows due to the nature of the laboratory (with three big windows and two doors). Nevertheless, such variation of the concentration was noted, and the results obtained gave an indication of the expected exposure during nail treatment activities.

Thirdly, the PID instrument sensitivity had no response to other chemicals such as formaldehyde. Thus, some critical chemicals used in nail products could not be included in the current study. Initially, the cancer risk was to be calculated however, because of the instrument not responding to the carcinogen (formaldehyde) only the non-cancer risks were calculated of the chemicals that were measured and detected by the instrument.

The instrument responded to one chemical at a time which was not ideal for this study as emissions of VOCs occur at the same time. Therefore, a mixture of total VOCs was used to obtain concentrations of the individual chemicals through a calculation using the correction factor and the amount of the chemical per product. Lastly, nail technicians often share the same area with hairdressers using e.g., hair dyes and other VOC contained products adding to chemicals potentially emitted into the environment. For the current study, this was not accounted for as the experimental study was solely on nail treatments.

4.7 Strengths of the study

The study obtained laboratory data that can be validated by field-based studies. Furthermore, the dose estimates made use of the mixture of default values and those obtained in the pilot study therefore, providing a scientific-based health risk assessment of the exposure scenarios used in this current study based on the South African informal nail salon industry. And this was the first study of its kind to provide baseline exposure data that can further be explored.

CHAPTER 5- SUMMARY AND CONCLUSIONS

This chapter summarises the main findings of the study and conclusions derived thereof. Despite the results achieving the study aim, there were knowledge gaps identified, giving rise to possible research avenues which are highlighted in this chapter. Lastly, irrespective of the knowledge gaps identified, the study contributed to the body of knowledge hence the significance of the study was emphasised.

5.1 Summary

Based on numerous studies, nail products such monomers and polymers, nail polishes, nail polish removers, glues, etc. have been associated with respiratory, neurologic, reproductive as well as carcinogenic health effects due to the VOC emissions emanating from the products. Furthermore, nail technicians are prone to such negative health effects because of the repeated use of the nail products to perform their daily activities as well as time spent in the nail salon setting.

Numerous field-based studies have measured the environmental concentration of the VOCs to quantify exposure amongst nail technicians. However, this has reported an underestimation of the exposure as the VOC concentration available in the environment does not necessitate concentration intake of the receptor. Despite the findings of field-based studies that the concentrations were below the occupational exposure limit, there was an increased number of reported health effects in the nail industry. Therefore, in addressing some of the pitfalls of the traditional method of quantifying exposure, this study considered the 21st -century approach of monitoring VOCs using real-time instrumentation. Furthermore, receptor-based factors, as well as environmental factors, were considered to obtain dose estimates. The dose estimates provided the basis to quantify exposure holistically instead of sole use of environmental concentration as a proxy for exposure. In summary, the study characterised exposure to VOCs by mimicking the acrylic as well as buff and paint nail treatments in a controlled laboratory environment.

5.2 Summary of main findings based on the study objectives

This section outlines the major findings presented based on the objectives of the study.

a) To measure concentrations of eight selected VOCs during nail treatment in a controlled laboratory environment.

There were two nail treatments namely acrylic as well as buff and paint that were performed in a controlled laboratory environment to mimic a real/field-based nail salon. For the acrylic nail treatment, the chemicals of interest were ethyl methacrylate and methyl methacrylate from the monomer and polymer, respectively, while the focus for buff and paint nail treatment was on butyl acetate, toluene, xylene, and ethyl acetate contained in the nail polish. Other chemicals included acetone and ethyl alcohol from the sanitiser. The concentration of the individual chemicals was calculated by multiplying the percentage composition of the chemical in the product to the average TVOC concentration then divided by 100. The results showed that methyl methacrylate, ethyl methacrylate, ethyl alcohol, acetone and ethyl acetate had a concentration greater than 100 mg/m^3 during a single nail treatment. Furthermore, given those nail technicians performed on average 7 treatments in a 9-hour shift, this resulted in a seven-fold increase. The current study shows an increased risk of exposure due to the number of treatments performed as well as the exposure duration might lead to a high probability of developing associated health effects. On the contrary, the reduction in the number of treatments and the exposure duration may significantly decrease the concentration and thus decreasing the risk of exposure and reduce the probability of developing health effects. However, it is important to note that other factors such as dose, cumulative exposure and biological make-up of the receptor can also influence the development of health effects and not merely the environmental concentration.

b) To characterise and compare exposure to TVOCs at multiple nail treatment activities.

For this objective acrylic along with buff and paint nail treatments were monitored to characterise emissions at multiple stages of the nail treatment. In each of the nail treatments, triplicates were obtained. The TVOC concentrations were averaged, and statistical tests performed. In acrylic nail treatment, it was found that the application of the monomer-polymer showed higher TVOC emissions of 2373 mg/m^3 which decreased with the introduction of ventilation to 1941,9 mg/m^3. The results were consistent with the high concentration of ethyl methacrylate and methyl methacrylate that were measured during acrylic nail treatment. There was statistical significance amongst all activities compared to the application of monomer-polymer paste. However, it was unexpected that there was no statistical significance between decanting and nail drying when ventilation was introduced. This is because wet surfaces have been reported to emit more VOCs compared to dry surfaces.

For the buff and paint nail treatment, the application of nail polish showed a higher TVOC emissions of 1820,6 mg/m^3 and with the introduction of ventilation, it decreased to 1496,8 mg/m^3. It can be argued that from the current study, the greater part of the emissions from the nail polish was ethyl acetate as the nail polish safety datasheet showed ethyl acetate had the highest percentage composition. There was no statistical significance between the wiping of nails with acetone and nail drying in the absence of ventilation. This might be due to the emission rate of the acetone decaying quicker therefore no accumulation of the acetone. Overall, this current study indicates that activities involving wet surfaces often lead to increased emission rates therefore, resulting in increased concentration of VOCs. Again, such results indicate that "wet" activities are high exposure risk in the nail treatment process and measures should be implemented focusing more on those activities.

c) To assess the efficacy of natural ventilation in controlling TVOC emissions.

To address this objective, acrylic as well as buff and paint nail treatments were monitored under two exposure scenarios, one with ventilation and the other without ventilation. Ventilation was introduced by opening one window and a door for one of the two exposure scenarios. Averages of the TVOC were calculated from data extracted from the monitoring instrument. Furthermore, a correction factor (PID sensitivity to a specific gas) was multiplied with the TVOC concentration to quantify chemicals using a single calibration gas. In the case of acrylic nail treatment, there was a two-fold decrease in the emissions when ventilation was introduced, yet with buff and paint, had a four-fold decrease in the emissions when ventilation was introduced. These results indicate the significance of natural ventilation in the reduction of exposure concentrations therefore, leading to a low risk of exposure to TVOCs during nail treatment activities. Additionally, during the characterisation of the TVOCs at multiple nail treatments it was evident that the distribution of VOC emissions did not change whether with ventilation and without ventilation. Therefore, this indicates that ventilation does not necessarily influence distribution but the accumulation of emitted VOCs hence the use of natural ventilation aids mixing and dilution and prevents accumulation of VOCs in the receptor's microenvironment as well as nail salon setting.

d) To assess the health risk of exposure to selected VOCs during the nail treatment process.

A health risk assessment on exposure to acetone, toluene, xylene, methyl methacrylate and ethyl acetate emitted during the nail treatment process in a controlled laboratory environment was conducted. For risk indices in the health risk assessment, the hazard quotients were used to understand the potential exposure and the probability of developing health effects. By obtaining the CDI (adj), it enabled the calculation of the hazard quotient (HQ) to derive the risk posed by the non-carcinogenic compounds on both male and female nail technicians. From the study, xylene had the same CDI (adj) for both males and females however the HQ differed (0.9 and 1.1 respectively). This showed that body weight as a parameter had a huge impact on the results of the HQ. Moreover, most of the compounds had an HQ>1 indicating that there is a potential of developing health effects linked to exposure. However, in the case of xylene exposure amongst male nail technicians, the results showed no risk of developing health effects (HQ<1).

Due to the dearth of lack of literature on health risk assessments in the nail salon industry, it has been difficult to fully understand the health risk amongst nail technicians. The results from the current study addressed health risk assessment amongst nail technicians using some exposure data obtained in the South African informal nail salon setting. Environmental concentration is vital in health risk assessment however, there are other factors that may influence exposure such as emission rate of the contaminant, exposure pathways, receptor's biological make-up as well as behaviour when performing activities.

5.3. Conclusion and significance

This study demonstrated that there are several factors that influence the characterisation of exposure pertaining to VOC emissions from nail treatments in nail salon settings. Such factors include VOC concentration, ventilation, type of nail treatment, time-activity patterns, and receptor-based variables (sex, body weight and inhalation rate). The study showed that the time-activity pattern of the nail technicians i.e., the number of nail treatments performed together with the exposure duration resulted in an increase in the risk of exposure to VOCs and subsequently increasing the probability of the developing associated health effects. Additionally, methacrylates had the highest concentration, and these are known to result in health effects ranging from allergic contact dermatitis to nervous system disorders.

Despite acrylic nail treatment emitting more TVOCs compared to the buff and paint nail treatment, this study established that buff and paint nail treatment had a high exposure risk compared to acrylic nail treatment. This was because of the carcinogenic related health effects associated with certain chemicals contained in nail polish which is used during the buff and paint nail treatment. Moreover, it was found that "wet" activities such as the application of monomer-polymer and nail polish resulted in increased emission of VOCs.

This study indicated that the absence of ventilation resulted in the accumulation of TVOC emissions in the receptor's microenvironment. This is evident from the 50% reduction in the TVOC emissions when opening windows and door to allow natural ventilation. Furthermore, this highlighted the efficacy of natural ventilation in aiding air exchange and dilution of the emissions to prevent the accumulation of TVOCs in the receptor's microenvironment.

For the health risk assessment, this study demonstrated that the CDI (adj) may be the same, but the probability of developing health effects is greatly influenced by other input parameters such as body weight. In the case of xylene, female nail technicians were more at risk of developing health effects compared to male nail technicians.

Overall, the information provided in this study will be useful for field-based studies in accounting for the often-neglected confounders such as risk estimates (considering environmental concentration, inhalation rate, the duration of exposure, average body weight and the exposure frequency) during health risk assessment. Additionally, the exposure data obtained may form part of the exposure data inventory focused on the South African informal nail salon industry. Moreover, this study may add value pertaining to assessing the risk associated with the nail products used in the informal nail salon industry in South Africa. Such risk-based information may influence the development, implementation, and monitoring of regulatory frameworks, especially in the informal nail salon industry.

5.4. Future research avenue

This study provided a basis for exposure data in the South African context and under a controlled laboratory environment. Therefore, there is a need for field-based studies that will validate the laboratory-based data. This will also ensure that parameters that were controlled in this environment are considered when analysing data from field-based studies. A more sensitive instrument is recommended that can detect especially the carcinogenic compounds which were one of the aspects that this study could not fulfil due to instrument sensitivity. Additionally, field-based studies should follow the pattern of obtaining dose estimates as such information is currently limited leading to the exposure being underestimated. The study was particularly focused on VOC; however, there is a need to also consider the particle emission and their size distribution especially during the filing and buffing processes. Overall, this information is necessary for closing the gap in most strategies that are focused on health promotion and exposure prevention.

6. References

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HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

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DATE: 20/11/2018

REF: *R14/49*

PROTOCOL NO: M171184 *(This is your ethics application study reference number. Please quote this reference number in all correspondence relating to this study)*

PROJECT TITLE: *Occupational exposure to chemicals and health outcomes amongst nail technicians in Johannesburg, South Africa*

Please find attached the Clearance Certificate for the above project. I hope it goes well and that an article in a recognized publication comes out of it. This will reflect well on your professional standing and contribute to the Government funding of the University.

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R14/49 Ms G Keretetse

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
CLEARANCE CERTIFICATE NO. M171184

NAME: **(Principal Investigator)**	Ms G Keretetse
DEPARTMENT:	School of Public Health Medical School University
PROJECT TITLE:	Occupational exposure to chemicals and health outcomes amongst nail technicians in Johannesburg, South Africa
DATE CONSIDERED:	24/11/2017
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Professors DH Brouwer and G Nelson
APPROVED BY:	CBPenny Dr CB Penny, Chairperson, HREC (Medical)
DATE OF APPROVAL:	20/11/2018

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary on 3rd floor, Phillip V Tobias Building, Parktown, University of the Witwatersrand, Johannesburg.
I/We fully understand the conditions under which I am/we are authorised to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated from the research protocol as approved, I/we undertake to resubmit to the Committee. **I agree to submit a yearly progress report**. When a funder requires annual re-certification, the application date will be one year after the date of the meeting when the study was initially reviewed. In this case, the study was initially reviewed in **November** and will therefore reports and re-certification will be due early in the month of **November** each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature ____________________ Date ____________________

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