A Thesis

entitled

Formaldehyde Exposure During Cadaver Transport

by

Michael David Weiler

Submitted to the Graduate Faculty as partial fulfillment of the requirements for the

Master of Science Degree in

Occupational Health

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April Ames, PhD, CIH, Committee Chair

_____

Farhang Akbar-Khanzadeh PhD, CIH, Committee Member

_____

Sheryl Milz, PhD, CIH, Committee Member

_____

Michael Valigosky, PhD, CIH, Committee Member

_____

Amanda Bryant-Friedrich, PhD, Dean
College of Graduate Studies

The University of Toledo

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An Abstract of

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Occupational formaldehyde exposure occurs during the embalming and preservation of cadavers as well as other work involving cadavers including moving, dissection, transportation, and cremation. This study examined formaldehyde exposure during the transportation of cadavers and dissected cadavers between medical universities in Ohio and during transportation between an Ohio and a Michigan medical university. Three events were sampled: one employee in one van during event one and two employees in separate vans during event two. Personal replicate samples were collected from the breathing zones of the workers during the cadaver transport. Transportation time included loading and unloading cadavers. A control vehicle was also sampled. Time-weighted average (TWA) exposure to formaldehyde ranged from 0.36 parts per million (ppm) (0.44 mg/m^3) to 0.49 ppm (0.60 mg/m^3). Eight-hour TWAs were below the Occupational Safety and Health Administration (OSHA) permissible exposure limit of 0.75 ppm (0.92 mg/m^3). The eight-hour TWAs were below the OSHA action level of 0.5 ppm (0.62 mg/m^3). All eight-hour TWAs exceeded the American Conference of Governmental Industrial Hygienists (ACGIH) ceiling value of 0.3 ppm (0.37 mg/m^3).

The formaldehyde concentrations by transportation method demonstrated a statistically significant difference between exposures during the cadaver transport, dissected cadaver transport and the control.

A special thank you to my wife Crystal for being a light in the tunnel especially before the end was in sight. And thank you and hugs to each of my sons Caedmon and Declan who sacrificed several nights of play-time with Daddy. This is as much yours as it is mine.

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Thank you Dr. Ames for your long hours of review and assistance. Your prodding and encouragement are likely responsible for the completion of this paper.

Also, thank you Beth Dalzell for your willingness to participate, share your profession, and open to me the world of embalming.

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List of Abbreviations

ACGIH.....American Conference of Governmental Industrial Hygienists
IARC.....International Agency for Research on Cancer
NIOSH .....National Institute for Occupational Safety and Health
OEL.....Occupational Exposure Limit
OSHA.....Occupational Safety and Health Administration
PEL .....Permissible Exposure Limit
REL.....Recommended Exposure Limit. Used by NIOSH.
TLV.....Threshold Limit Value. Used by ACGIH.
TWA .....Time Weighted Average

Chapter 1

Introduction

1.1 Overview

Formaldehyde is a ubiquitous substance that can be found in small amounts in the human body, larger amounts in the environment, and many consumer products. However, formaldehyde is mainly known for its use in embalming fluid. Ample gross anatomy lab students are familiar with its pungent smell and irritating properties while dissecting preserved specimen, but irritation of the eyes, nose, and throat isn't the only concern during formaldehyde exposure. Formaldehyde has been classified as a human carcinogen by the International Agency for Research on Cancer (IARC, 2006). Cancer may be of particular concern for those occupationally exposed repeatedly over time such as gross anatomy laboratory instructors and embalmers who consistently work around preserved cadavers. For efficiency and purposes of this paper, the term cadaver will be used henceforth to describe human bodies preserved by embalming and are not dissected.

Transportation of cadavers is another potential exposure point for medical workers since cadavers contain and have been shown to release formaldehyde (Ohmichi et al., 2006). Cadaver transportation is important to medical universities who do not perform embalming due to time constraints, convenience, or a lack of resources due to

their small size. In this study, workers were personally monitored during activities associated with cadaver and dissected cadaver transportation.

1.2 Statement of Problem

Acute and chronic health effects have been demonstrated to occur from exposure to formaldehyde (IARC, 2006; Hauptmann et al., 2004; Hauptmann et al., 2009; Krzyzanlwski et al., 1990; Sauder et al., 1986). Studies examined exposure to formaldehyde in gross anatomy labs by students and instructors and found elevated levels (Akbar-Khanzadeh et al., 1994; Akbar-Khanzadeh and Mlynek, 1997). However, to the best of the author's knowledge, there are no known studies on exposure to formaldehyde during transportation of formalin-preserved cadavers. Workers have potential to be exposed to formaldehyde during cadaver transportation in an enclosed space which may increase formaldehyde concentration and thereby increase the potential for acute and chronic health effects. Employees involved with transportation may have other occupational exposures to formaldehyde such as those received during embalming or working in a gross anatomy lab.

1.3 Significance

No research or worker exposure data was identified by the author relating to formaldehyde during transport of cadavers, for reasons including: body donation, body loan between medical facilities or universities, or cremation services. The current study evaluated formaldehyde exposure of an anatomy lab manager during cadaver transportation, including loading and unloading, through collection of personal air samples from the breathing zone. Eight-hour time weighted averages were determined and compared to occupational exposure limits. In addition, short term exposure during

the unloading of cadavers was evaluated. An evaluation of possible controls to protect worker health was also performed.

1.4 Hypotheses

The following hypotheses will be evaluated:

1. There is no statistically significant difference in formaldehyde concentrations during transportation of cadaver transport, dissected cadaver transport and a control.
2. The median 8-hour time weighted average (TWA) formaldehyde concentration, obtained during transportation of cadavers and dissected cadavers, including loading and unloading, does not exceed the current Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) of 0.75 ppm (0.92 mg/m^3).
3. A short-term sample (15-minutes), collected during unloading of dissected cadavers, does not exceed the current OSHA short term exposure limit (STEL) of 2.0 ppm (2.46 mg/m^3).

1.5 Objectives

The following objectives were set during the study:

- Personal formaldehyde samples were collected during transportation of cadavers between medical universities;
- Personal formaldehyde samples were collected during transportation of dissected cadavers between medical universities;
- Personal formaldehyde samples were collected during loading and unloading of cadavers and dissected cadavers;

- One 15-minute short term personal sample was collected during dissected cadaver unloading;
- Eight-hour personal formaldehyde levels were quantified during transportation of cadavers, dissected cadavers, and loading and unloading;
- Eight-hour TWAs were compared to OSHA PELs and 15-min samples to OSHA STELS;
- Control samples collected to and from each location; and,
- Option(s) for controlling exposure to formaldehyde during the transportation process were provided.

Chapter 2

Literature Review

2.1 Introduction to Formaldehyde

In 1867, formaldehyde was identified by German chemist August Wilhelm von Hofmann. It is a colorless, flammable gas and is soluble in water. Commercially, it can be purchased as formalin which is typically 37% by weight or 40% by volume of formaldehyde gas in water (Raja et al., 2012). The smell of formaldehyde is pungent and irritating.

2.2 Formaldehyde and Human Activity

Environmentally, the Agency for Toxic Substances and Disease Registry (ATSDR) recognizes most formaldehyde is released into the atmosphere by human activities. Releases of formaldehyde occur from power plant emissions, vehicle exhaust, and tobacco smoke. Formaldehyde may also be released from the production, use, and disposal of formaldehyde-based products and migrate into rain and surface water (ATSDR, 1999).

Formaldehyde can be found in industrial products such as textiles, adhesives, plastic, cosmetics, fertilizers, paper, and other pressed wood products. (Bernstein et al., 1984) It can also be found in construction insulations, concrete, glass frames, fire

extinguishers, toothpaste, deodorants, disinfectants, ink, and photographs. (Inci et al., 2013).

Formaldehyde is used by medical professionals such as pathologists and histologists for tissue examination and diagnosis procedures (Inci et al., 2013). It is also used in the preparation of cadavers for extended storage and examination. Such cadavers are commonly used in gross anatomy laboratories to educate students pursuing careers in the medical field (Patil, 2014).

2.3 Embalming

Embalming may consist of one or more of four parts: arterial embalming, cavity embalming, hypodermic embalming, and surface embalming. Arterial embalming is the primary embalming process used and referenced in this study. In the process of arterial embalming formalin and other embalming aides such as citrates are injected into the blood vessels, usually initiated at the right common carotid artery. Blood is simultaneously drained from the right jugular vein. An embalming machine is used to inject and pump embalming solution throughout the body while an embalmer may massage the solution into cadaver tissue to ensure full and proper distribution of the fluid. Other points of injection may be used in cases of poor circulation or incomplete distribution (Batra et al., 2010).

Formalin has been the most common and most preferred fixing agent due to its ability to prevent deterioration of tissue but also its preservation of flexibility. As stated by Sigma-Aldrich,

> "If properly preserved, the cell and tissue constituents should appear in as lifelike a manner as possible. In reality each fixative creates a unique set

of artifacts. The living cell is fluid, or in a semi-fluid state. Formaldehyde is both a non-coagulant and an additive fixative. Formalin fixation is thought to form cross links between the aldehydes and the proteins, creating a gel, thus retaining cellular constituents in their in vivo relationship. Once properly fixed, the tissue should be able to withstand the subsequent stages of tissue processing or staining (Sigma)."

2.4 Formaldehyde in the Body

Formaldehyde may enter the body through the skin, digestive system, or respiratory system. It may be ingested in "fresh water, sugar, coffee, fruits and vegetables, drugs and the protective additives in some foods." Formaldehyde is also commonly found in cigarette smoke, smoke from burning wood or liquid fuels, or fumes from paints used for surfaces thereby creating exposure from inhalation (Inci et al., 2013).

Formaldehyde is naturally occurring in human tissue in a range from 3 to 12 ng/g of tissue and at any given time 40% is unbound. Exogenous intake of formaldehyde may occur through ingestion, respiration, dermal contact, or injection but is metabolized similarly despite the mode of entry. The liver and erythrocytes metabolize formaldehyde to formic acid which is excreted either in feces or urine. Formaldehyde cannot be stored by the body and complete elimination happens within a few days (Inci et al., 2013).

While it is most commonly found in liquid form as formalin, formaldehyde easily releases from liquid into the atmosphere as a gas creating the most common route of exposure: inhalation. Formaldehyde evaporation rate increases with an increase in temperature, relative humidity, or both (Myers, 1985).

2.5 Non-carcinogenic Effects

2.5.1 Irritation

Formaldehyde exhibits high irritant properties with anecdotal reports of particular irritation of the eyes, skin, and respiratory system. Irritation due to formaldehyde is not debated though the maximum level of tolerance is around 5 ppm with actual tolerance levels being subject dependent (Smith, 1992).

Several studies have reported the irritation responses of medical students while dissecting and/or observing cadavers preserved with formalin. All studies reported a majority of subjects exhibiting at least one irritating aspect of formaldehyde exposure (Patil, 2014; Vimercati et al., 2010; Onyije et al., 2012; Akbar-Khanzadeh et al., 1994; Akbar-Khanzadeh and Mlynek, 1997).

2.5.2 Sensitization

A sensitizer is defined by OSHA as "a chemical that causes a substantial proportion of exposed people or animals to develop an allergic reaction in normal tissue after repeated exposure to the chemical (OSHA, 2016)." The American Conference of Governmental Industrial Hygienists (ACGIH) recognizes formaldehyde as a skin sensitizer and is noted in Threshold Limit Value Handbook (2016). Sensitization is commonly shown through contact dermatitis. It is unclear if formaldehyde causes respiratory sensitization although systemic sensitization has been revealed in hemodialysis patients after years of treatment; however, it is rare (Smith, 1992).

2.5.3 Pulmonary Function

Several studies show changes in pulmonary function after exposure to formaldehyde. In 1990, a study performed on plywood workers set the ground work for

further investigating this link. Malaka and Kodama (1990) found a significant relationship between plywood workers occupationally experiencing long-term exposure to formaldehyde and reduced respiratory function. Asthma is a chronic condition of reduced respiratory function where airways are constricted but there is no clear correlation between its occurrence and formaldehyde exposure (Kriebel et al., 2001).

A study in 1994 found over 94 percent of 34 gross anatomy workers were exposed in excess of the American Conference of Governmental Industrial Hygienists recommended ceiling value of 0.3 ppm. These workers exhibited statistically significant decreases to forced vital capacity (FVC) and forced expiratory volume in three seconds (FEV_3) serving as markers for decreased pulmonary function. It was also found that exposure to formaldehyde was significantly higher when examining deep cavity structures compared to superficial structures of dissected cadavers (Akbar-Khanzadeh et al., 1994).

Another study in 1997 examined respiratory function within medical students after one hour and three hours of exposure. Both exposed subjects and control subjects experienced increased respiratory function. This, however, is possibly explained by expected natural diurnal changes in respiratory function. Subjects exposed to formaldehyde experienced significantly less increases in respiratory function presumably due to formaldehyde exposure (Akbar-Khanzadeh et al., 1997).

2.6 Carcinogenic Effects

According to the International Agency for Research on Cancer (IARC), formaldehyde has been classified as a human carcinogen. It has been shown to cause nasopharyngeal cancer and likely causes leukemia (IARC, 2006). The IARC specifically

concluded there is “strong but not sufficient evidence for a causal association between leukemia and occupational exposure to formaldehyde.” This determination was derived from updates to two primary industrial cohort studies examining workers exposed to formaldehyde (Pinkerton et al., 2004; Hauptmann et al., 2003). Some authors may disagree about the link between formaldehyde and leukemia claiming a lack of evidence formaldehyde can reach certain tissues beyond those directly contacted, damage is caused to target cells necessary to initiate leukemogenesis, and “no credible experimental animal model for formaldehyde-induced leukemia (Zhang et al., 2009).” However, the determination of a 2009 meta-analysis with a 2010 update still reports “evidence of an association with leukemia, particularly of the myeloid type (Zhang et al., 2009; Schwilk et al., 2010).”

One meta-analysis found a small increase of pancreatic cancer among embalmers, pathologists, and anatomists though recognized no increase among industrial workers who had the highest exposures to formaldehyde. The link between formaldehyde exposure and pancreatic cancer is under similar scrutiny as that of leukemia due to biological plausibility (Collins et al., 2001). That being said, “airborne exposures greater than 0.1 ppm appear to be at risk for cancer of the lung, pharynx, buccal cavity, liver, bone, skin, prostate gland, bladder, kidney, and eye (Ryan et al., 2003).”

2.7 Gross Anatomy Lab Exposures

During each year from 2012 to 2014, nearly 50,000 new medical licenses were issued to physicians from state medical boards. At one time, each physician was a medical student most likely in a gross anatomy lab and exposed to formaldehyde from a preserved cadaver (Young et al., 2015).

Multiple studies have found gross anatomy lab students exposed to formaldehyde over limits recommended by OSHA, the National Institute for Occupational Safety and Health (NIOSH), and ACGIH. One study collected midget impinger area samples over 29 days in a medical college gross anatomy lab with 38 cadavers. All subjects were overexposed when compared to the ACGIH TLV ceiling of 0.3 ppm while nearly a third (29.5%) were overexposed when compared to the OSHA PEL of 0.75 ppm (Akbar-Khanzadeh & Park, 1997).

Akbar-Khanzadeh and Mlynek (1997) performed a study to determine changes in respiratory function after one and three hours of exposure to formaldehyde in a gross anatomy laboratory. A total of 86 non-smoking subjects participated in the study. The study group included 50 first year medical students. The students wore gloves, goggles and lab coats during the procedures and worked in the gross anatomy lab with 38 cadavers. Nose irritation was reported by 82% of the study subjects and eye irritation was reported by 76% of the study subjects. Respiratory function increased in study subjects for one and three hours of exposure. This study also confirmed the irritability of formaldehyde (Akbar-Khanzadeh & Mlynek, 1997).

Akbar et al. (1994) found nearly one-third of workers in a gross anatomy laboratory in excess of the OSHA Permissible Exposure Limit (PEL) 0.75 ppm formaldehyde exposure placing them over the recommended limits of ACGIH and NIOSH as well (Akbar et al., 1994). Ryan et al. (2003) also found a portion of sampled students and instructors in a gross anatomy lab over the OSHA PEL. The same study found teachers and teaching assistants to have higher levels of exposure than students

(Ryan et al., 2003). Generally speaking, personal exposure to formaldehyde can be expected to be higher as distance to the source decreases.

2.8 Cadaver Transport

No literature was found examining formaldehyde exposure during transport of cadavers for any reason including body donation, body loan between medical facilities or universities, cremation other funeral necessities. This study is intended to initiate bridging this gap by examining transportation of cadavers and dissected and loaned between medical universities.

2.9 Exposure Guidelines

A full-shift Time-Weighted Average (TWA) is a calculated average exposure for a period of time, usually eight hours, unless otherwise specified. The goal of a TWA is to protect workers against chronic health conditions due to repetitive and consistent exposure. It assumes the variation of exposure levels will not have a significant impact of result. Workers may exceed the permissible exposure TWA by three times the limit for no longer than a half hour but must never exceed the TWA limit by five times (Fuller, 2016). OSHA sets the full shift TWA at 0.75 ppm (0.92 mg/m^3) for formaldehyde (OSHA, 2016). NIOSH is a research agency that recommends 0.016 ppm (0.20 mg/m^3) (for the full shift TWA exposure limit (NIOSH, 2016).

A short-term exposure limit or STEL protects against acute health hazards seen during some short-term chemical exposures. STELs are a set limit value not to be exceeded in a short amount of time, typically a 15-minute period. The STEL must not be exceeded more than four times in an eight-hour shift. The STEL is typically a higher value than the TWA but is not intended to set a standard for long-term exposure (Fuller,

2016). OSHA's STEL is 2 ppm (2.46 mg/m^3) (OSHA, 2016). NIOSH provides a ceiling (15-minute) recommended exposure limit of 0.1 ppm (0.12 mg/m^3) (NIOSH, 2016).

The ceiling limit is a value not to be exceeded at any time. This is to protect against chemicals that produce immediate adverse health effects known to occur at a specific concentration (Fuller, 2016). ACGIH sets a ceiling for formaldehyde at 0.3 ppm (0.37 mg/m^3) (ACGIH, 2016).

OSHA also sets an action level of 0.5 ppm (0.62 mg/m^3) which mandates if this level is exceeded as an 8-hr TWA a medical surveillance program must be available to employees. A medical surveillance program must include examination by a physician and a medical disease questionnaire inquiring about signs and symptoms of potential exposure to formaldehyde. The medical surveillance program will assist in identifying employees with increased risk of exposure and evaluate the possible benefit of respirator use for these employees (OSHA, 2016).

Chapter 3

Methods

3.1 Overview

The purpose of this study was to evaluate formaldehyde levels released from cadavers during their transport to medical facilities. The term cadaver is used to describe human bodies preserved by embalming and are not dissected. At the location studies, the anatomy lab supervisor is the primary transporter but often recruits assistance from other workers to load, unload, and drive a second cargo van. The lab supervisor and some workers involved have other responsibilities and potentials for exposure to formaldehyde such as teaching gross anatomy, embalming cadavers, and completing paperwork in an area connected to the gross anatomy lab. The anatomy lab supervisor self-estimated personal time in areas with potential for formaldehyde exposure is approximately 30 hours per week. This study is intended to evaluate the portion of formaldehyde exposure the anatomy lab manager and assistants received during cadaver and dissected cadaver transport. Personal monitoring was used to quantify individual exposure.

3.2 Study Location

Personal sampling occurred during two transportation events in 2016. The first took place on May 16th to a university approximately three hours away in Ohio. The second event was on June 10th to a different university approximately 1.5 hours away in Michigan. The cadavers were stored until the time of transport at a medical university in northwest Ohio.

3.3 Transport Process

The cargo van manufacturer states the cargo area has a length of 87.2 inches, width of 60.4 inches, an interior roof height of 51.8 inches, for a total volume of 131.7 cubic feet (with wheel wells impeding the space). The driver and passenger seating area was connected to the cargo area as seen in Figure 3-1 and therefore shared the same atmospheric conditions. Each driver was accompanied by a passenger who took notes on driver behaviors such as when windows were open or closed. It is expected passengers had similar formaldehyde exposures as drivers but the passengers were not monitored.

After embalming, cadavers were heat sealed in a plastic bag, enclosed in a zippered vinyl bag, and stored in a walk-in cooler until needed for dissection or transportation. On the day of transportation, the anatomy laboratory staff used a gurney to move the cadavers from the walk-in cooler to a loading dock where they were placed in the rear of a cargo van. The lab staff noted the heat sealing process may be temperamental and inconsistent at providing a leak-proof enclosure. The vinyl bags used were thin and did not have handles making them prone to tears and leaks as bodies are moved or adjusted. During the loading process formalin may release from the cadaver bag.

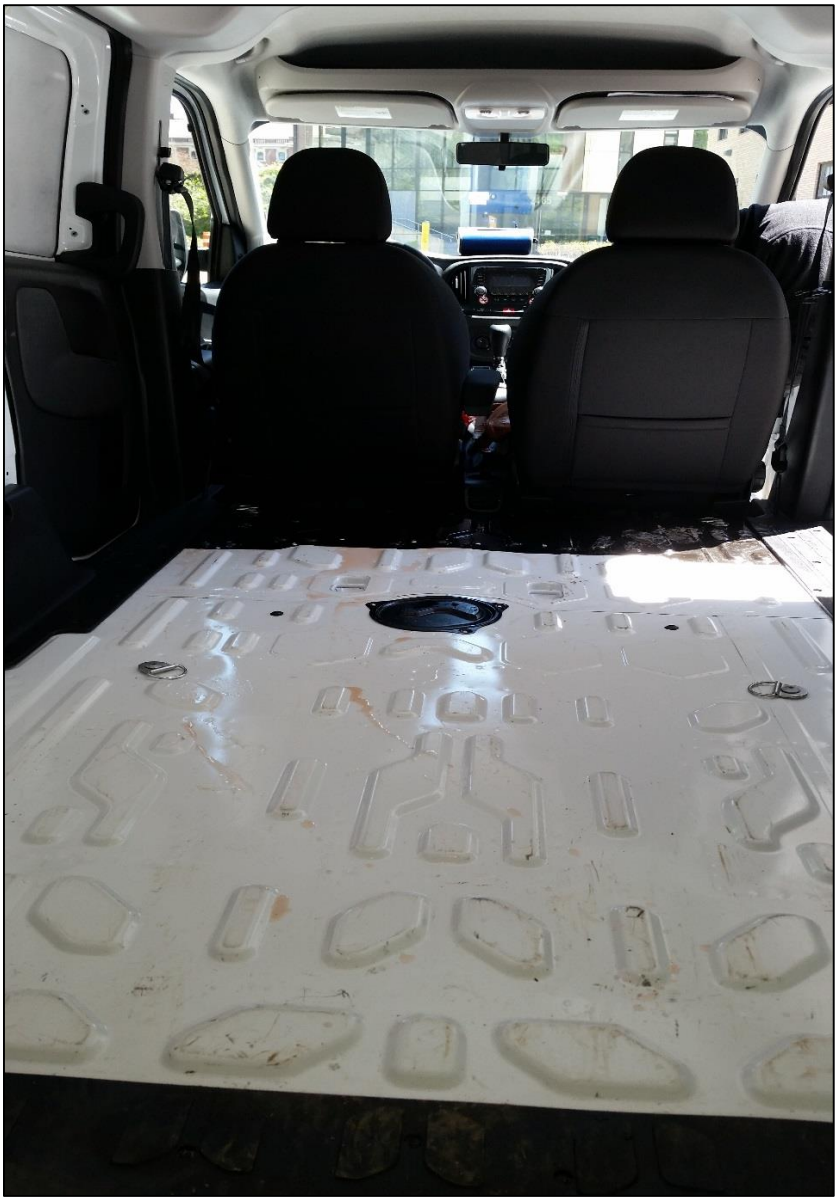

Figure 3-1 Rear of Transport Van

Transportation included one destination per day. Upon arrival to the destination facility, the bodies were unloaded and moved to the destination gross anatomy lab using gurneys. At the destination facility, dissected cadavers, being returned from loan to be prepared for cremation, were brought to the cargo van and physically loaded into the rear of the van. No heat-sealing bags were used on dissected cadavers. The dissected cadavers

were transported back to the medical university in northwest Ohio where they were unloaded to the gross anatomy lab and prepared for pickup by a cremation company. Cremation preparation includes placing the body in a sturdy wooden box.

3.4 Sampling Equipment

The equipment used to collect air samples and associated data is summarized below.

SKC AirLite® Model 110-100 personal air sampling pumps (Figure 3-2) Flow rates range from 1000 to 3000 ml/min and low flow rates range from 5 to 500 ml/min, with an adjustable low flow adaptor and constant pressure controller (CPC). The error range is ± 5 percent. The operating temperature range is 32 to 104 F (0 to 40 C). The pumps are powered by three standard AA alkaline batteries.

Figure 3-2 SKC AirLite pump

Constant Pressure Controller (SKC 224-26CPC-20) and Adjustable Low Flow Tube Holder (SKC 224-26-01). The CPC is an accessory for the AirLite Sampling Pumps that is used with an Adjustable Low Flow Tube Holder (Figure 3-3). The CPC is used as a pressure regulator to maintain a constant 20 inches water back pressure across the needle valve(s) of the Adjustable Low Flow Holder.

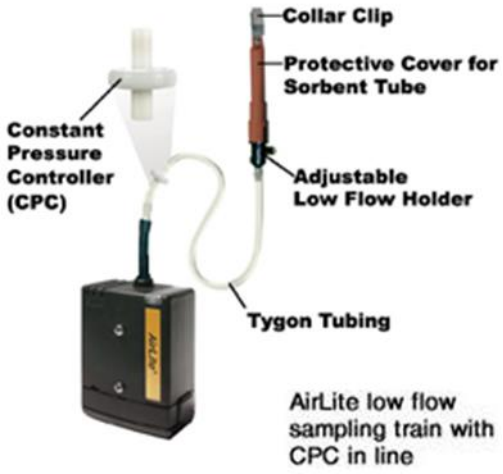

Figure 3-3 Sample Train Setup

BIOS DryCal® DC-Lite Model Number DCL-M Revision 1.08 (Serial Number 5327). The DryCal is a primary calibrator (Figure 3-4) with a flow range of 100 ml/min to 7 L/min, ±1 percent.

Figure 3-4 BIOS DryCal

SKC Sorbent Sample Tubes (226-119). Sorbent tubes (6-mm outside diameter (OD) x 110-mm length) were used to collect the air samples during active sampling (Figure 3-5). The tubes have a maximum flow rate of 500 ml/min. The tubes contain 300-mg front section and 150-mg backup sorbent section. The high purity silica gel inside the tube is coated with 2, 4-dinitrophenylhydrazine (DNPH). Formaldehyde and other aldehydes

react with DNPH to form stable hydrazones, which are extracted from the silica gel and analyzed by liquid chromatography. Sample tubes were stored in a freezer until use and again until they were shipped to a laboratory for analysis.

Figure 3-5 Sorbent Tubes

TSI Q-Trak Model 7575. The Q-Trak measures temperature and relative humidity (Figure 3-6). Temperature is measured using a thermistor sensor with a range of 32 to 140°F (0 to 60°C). The accuracy is ±1.0°F (0.56°C) and the resolution is 0.1°F (0.06°C). The response time of the instrument is 30 seconds. Relative humidity (RHis measured using a thin-film capacitive sensor with a range of 5 to 95%. The accuracy is ±3% RH and the resolution is 0.1% RH. The instrument response time is 20 seconds. Increases in temperature or relative humidity contribute to an increase in the emission rate of formaldehyde thereby increasing exposure to local workers.

Figure 3-6 TSI Q-Trak

3.5 Sampling Activities

Personal and area samples were collected during activities associated with cadaver transport and summarized below for Event 1:

- Transport of cadavers to an Ohio medical university: 1) two sampling pumps collected paired personal samples from the left and right side breathing zone of Employee 1; 2) one area sample was collected from the rear of the transport vehicle near the cadavers;
- Transport of dissected cadavers to the northwest Ohio medical university: 1) two sampling pumps collected paired personal samples from the left and right side breathing zone of the Employee 1; 2) one area sample was collected from the rear of the transport vehicle near the cadavers;
- One 15-minute STEL was collected from the breathing zone of Employee 1 during the unloading of the dissected cadavers; and,
- Control: one control sample was collected from a separate vehicle.

Personal and area samples were collected during activities associated with cadaver transport and summarized below for Event 2:

- Transport of cadavers to a Michigan medical university using two vans: 1) two sampling pumps collected paired personal samples from the left and right side breathing zone of Employee 1, the driver of van 1; 2) two sampling pumps collected paired personal samples from the left and right side breathing zone of Employee 2, the driver of van 2;
- Transport of dissected cadavers to the northwest Ohio medical university: 1) two sampling pumps collected paired personal samples from the left and right side

breathing zone of Employee 1, the driver of van one; 2) two sampling pumps collected paired personal samples from the left and right side breathing zone of Employee 2;

- One personal sample was collected from the breathing zone of Employee 1 during all loading and unloading activities; and,
- Control: one control sample was collected from a separate vehicle.

3.6 Pre-sampling Calibration

Pre-sampling calibration procedures were as follows:

- The air sampling pumps were turned on and allowed to warm up for five minutes;
- A silica gel sampling tube was removed from the freezer and used for calibration procedures;
- Using a short length of flexible tubing, the CPC outlet was connected to the sampling pump inlet;
- The inlet of the CPC was connected to the adjustable low flow holder connected to flexible tubing;
- The ends of the sampling tube were broken and inserted into the adjustable low flow holder;
- A second flexible tubing section was connected to the BIOS DryCal primary calibrator;
- The flow was adjusted to 0.1 liters/min; and,
- Once the flow was achieved, three trials were performed, recorded and averaged as the pre-sampling flow rate.

3.7 Sample Collection

Personal air samples were collected in the following manner:

- New batteries were placed in each air sampling pump;
- Sample tubes were removed from the freezer and labeled with a unique identification number;
- Using a short length of flexible tubing, the constant pressure controller outlet was connected to the sampling pump inlet;
- The inlet of the CPC was connected to the adjustable low flow holder;
- Immediately prior to sampling, the ends of the sorbent sampling tube were broken and inserted in the adjustable low flow holder. The direction of the sampling tube was with the arrow pointing towards the pump;
- A protective cover with collar clip was placed over the sorbent sampling tube and tightened;
- The collar clip with sampling tube was attached to the worker's collar, in their breathing zone (9-12 inches from worker's nose and mouth). Two personal samples were collected from the worker, one on the left side and another on the right side of the lapel;
- The sampling pump was turned on and the start time recorded;
- The workers tasks were documented during the sampling activities;
- After the specified time, the pumps were stopped and the time recorded;

- The sample tubes were removed from the sampling train, both ends were capped and the samples were placed on ice for transport to the lab;
- Each sampling day one blank was collected. A sorbent tube was broken and allowed to remain open for approximately ten seconds then capped at both ends and put on ice; and,
- Environmental conditions including ambient temperature, and relative humidity were logged each minute by the Q-Trak. The instrument was placed in the center and midline of the vehicle compartment.

3.8 Post-sampling

The steps of the pre-calibration were performed, except the flow rate was not adjusted. Three flow rates were recorded and averaged as the post-sampling flow rate. The average flow rate was determined by averaging the pre- and post-sampling flow rates. The average post-flow rates were verified to be within ±5 percent of the pre-sampling flow rates.

3.9 Laboratory Analysis

Sorbent tubes were transported on ice to Bureau Veritas Laboratory in Novi, Michigan. NIOSH method 2016 was used to analyze formaldehyde samples by high pressure liquid chromatography. Bureau Veritas is accredited by the Industrial Hygiene Laboratory Accreditation Program (IHLAP). A chain of custody was completed and accompanied the shipment.

3.10 Data Analysis

Descriptive statistics were used to summarize and tabulate data. The paired t-test was used to examine the differences between formaldehyde concentrations of side-by-

side samples for quality assurance. Kruskal-Wallis non-parametric, distribution free, analysis was performed using the formaldehyde concentrations based on cadaver transportation modes (cadaver, dissected cadaver, control). A significance level of 0.05 was used.

The Mann-Whitney U test was subsequently performed on statistically significant Kruskal-Wallis results to determine independent comparisons of formaldehyde concentrations based on cadaver transportation (cadaver, dissected cadaver, and control). Since there were multiple comparisons, the Bonferroni adjustment was used to adjust the observed significance level for the number of multiple comparisons that were made for each group of data.

A one-sample Wilcoxon Signed-Rank Test was performed to determine whether the median 8-hour time-weighted-average exceeded the OSHA PEL. All statistical analyses were performed using SPSS 23.

Chapter 4

Results

4.1 Overview

Air sampling took place during the transportation of cadavers and dissected cadavers on two separate days, May 16, 2016 (Event 1) and June 16, 2016 (Event 2). The term cadaver is used to describe human bodies preserved by embalming and are not dissected. The results from sampling along with calculated time-weighted averages are presented. One van and one employee were used for transport during Event 1 and two vans with one employee in each van were used for transport during Event 2. Transportation time included loading and unloading cadavers. The highest concentrations were seen during the transportation of cadavers during Event 2.

4.2 Formaldehyde Replicate Samples

Table 4.1 summarizes all personal replicate samples collected during the two cadaver transportation events. Statistical analysis of six replicate samples, collected on both right and left shoulders of employees, showed that the levels of formaldehyde were not significantly different ($p=0.942$). For data analysis, formaldehyde concentrations of replicate samples were averaged and reported as the personal exposure values. There was one instance a pump malfunctioned during Event 2 and one of the replicate samples was

determined to be invalid. In this case, the value of the remaining valid replicate sample was included in the data analysis.

Table 4.1 Replicate Samples during Cadaver Transportation

Sample description*	Total sample time (min)	Concentration (ppm)
Event 1		
Cadaver Transport		
Employee 1 (right); Van 1	147	1.1
Employee 1 (left); Van 1	147	0.90
Dissected Cadaver Transport		
Employee 1 (right); Van 1	118	0.23
Employee 1 (left); Van 1	118	0.23
Event 2		
Cadaver Transport		
Employee 1 (left); Van 1**	118	0.020
Employee 1 (right); Van 1	118	1.4
Employee 2 (right); Van 2	120	1.7
Employee 2 (left); Van 2	120	1.5
Dissected Cadaver Transport		
Employee 1 (left); Van 1	110	0.12
Employee 1 (right); Van 1	110	0.13
Employee 2 (right); Van 2	118	0.01
Employee 2 (left) ; Van 2	118	0.44

*right/left refer to sample media location
**sample invalid due to pump malfunction

4.3 Formaldehyde Concentrations during Cadaver Transport

Table 4.2 summarizes various samples collected during the two cadaver transportation events. One van and one employee were evaluated during Event 1. Six cadavers were taken to a medical university and twelve dissected cadavers were transported on the return trip. Two vans and two employees were evaluated during Event 2 with van one and two taking eleven cadavers each to a medical university. On the

return trip, van one transported thirteen dissected cadavers and van two transported eight dissected cadavers.

A control vehicle with no cadavers was sampled during each of the events. Control vehicles travelled the same route as the cargo vans and were used to simulate travel conditions without exposure to formaldehyde from cadavers. A personal vehicle, approximately 10 years of age was used as a control vehicle during Event 1, while a rental vehicle was used during Event 2, which was less than a year old. Measured concentrations in the control vehicles ranged from 0.002 ppm (0.003 mg/m^3) during Event 1 to 0.01 ppm (0.012 mg/m^3) during Event 2.

One short-term sample was collected during unloading of dissected cadavers (0.04 ppm; 0.05 mg/m^3) along with area samples collected from the rear of the van during Event 1. Area samples were found to be similar to personal exposure and were not collected during Event 2. The average personal exposure samples from each event are reported based on the average of the replicate samples. Field blank samples were collected each day similar to active samples, except no air was passed through the sampling media. Results from both field blanks were below the limit of detection (<0.1 µg).

Employee 1 formaldehyde concentrations during Event 1 ranged from 0.23 ppm (0.29 mg/m^3) during dissected cadaver transport to 1.0 ppm (1.2 mg/m^3) during cadaver transport. Results for Employee 1, during Event 2, ranged from 0.13 ppm (0.16 mg/m^3) during dissected cadaver transport to 1.4 ppm (1.7 mg/m^3) during cadaver transport. Event 2 concentrations for Employee 2 ranged from 0.22 ppm (0.27 mg/m^3) during dissected cadaver transport to 1.6 ppm (2.0 mg/m^3) during cadaver transport. The

formaldehyde concentration during cadaver and dissected cadaver loading and unloading by Employee 1 was 0.08 ppm (0.10 mg/m^3).

Table 4.2 Formaldehyde Concentration during Cadaver Transportation

Sample description	Total sample time (min)	Concentration (ppm)
Event 1		
Cadaver Transport (Van 1 = 6 cadavers)		
Employee 1, Van 1, personal sample	147	1.0
Van area	149	0.98
Dissected Cadaver Transport (Van 2 = 12 dissected cadavers)		
Employee 1, Van 1, personal sample	118	0.23
Van area	118	0.23
Unloading dissected cadavers	15	0.040
Control	241	0.0020
Event 2		
Cadaver Transport (Van 1 = 11 cadavers, Van 2 = 11 cadavers)		
Employee 1, Van 1, personal sample	118	1.4
Employee 2, Van 2, personal sample	120	1.6
Dissected Cadaver Transport (Van 1 = 13 dissected cadavers, Van 2 = 8 dissected cadavers)		
Employee 1, Van 1, personal sample	110	0.13
Employee 2, Van 2, personal sample	118	0.22
Other		
Cadaver and dissected cadaver loading and unloading	216	0.080
Control	222	0.010

Field blanks all below the limit of detection (<0.1 µg)

Descriptive statistics are described in Table 4.3. The median formaldehyde concentration during cadaver transport was 1.4 ppm (1.7 mg/m^3) with a range from 1.0 to 1.6 ppm (1.2 to 2.0 mg/m^3). The median formaldehyde concentration during dissected

cadaver transport was 0.22 ppm (0.27 mg/m^3) with a range of 0.13 to 0.23 ppm (0.16 to 0.29 mg/m^3) as seen in Figure 4-1.

Table 4.3 Descriptive Statistics Cadaver Transportation (ppm)

Sample description	n	Median	25th percentile	75th percentile	Minimum	Maximum
Cadaver transport	3	1.4	1.2	1.5	1.0	1.6
Dissected cadaver transport	3	0.22	0.17	0.23	0.13	0.23
Control	2	0.010	0.0020	0.010	0.0020	0.010

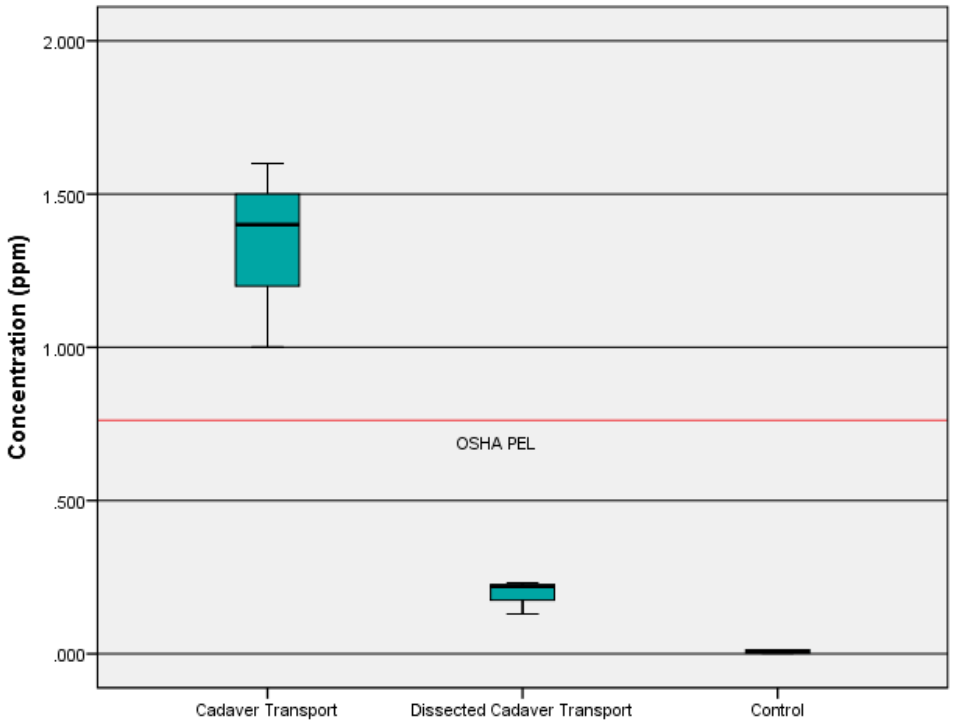

Figure 4-1 Formaldehyde Concentration by Transportation Mode

4.4 Temperature and Relative Humidity

Table 4.4 summarizes all environmental data collected during Event 1 and Event 2. Temperature and humidity can affect formaldehyde emission rate. Increases in either will increase the rate formaldehyde releases into the atmosphere. The average

temperature and relative humidity for Event 1 are 21.5 ºC (70.7ºF) and 31.1% respectively. Temperature ranged from 13.6 to 27.4 ºC (56.6 to 81.3ºF). Relative humidity ranged from 19.3% to 46.0%. The average temperature and relative humidity for Event 2 are 27.2 ºC (80.9 ºF) and 34.8% respectively. Temperature ranged from 25.1 to 31.6 ºC (77.1 to 88.8 ºF). Relative humidity ranged from 25.4% to 52.7%.

Table 4.4 Atmospheric conditions

	Mean	**Minimum**	**Maximum**
Event 1			
Temperature (C)	21.5	13.6	27.4
Relative Humidity (%)	31.1	19.3	46.0
Event 2			
Temperature (C)	27.2	25.1	31.6
Relative Humidity (%)	34.8	25.4	52.7

4.5 Kruskal-Wallis by Cadaver Transportation Mode

The Kruskal-Wallis test was performed by transport method: cadavers, dissected cadavers and control. Results for comparison of transportation method indicates that there is a statistically significant difference in the distribution of formaldehyde concentrations between the groups (p=0.044). The Mann-Whitney U-test (post-hoc) was then used to test the distribution of formaldehyde concentrations for the 1) cadaver transport and dissected cadaver transport; 2) cadaver transport and control; and, 3) dissected cadaver transport and control. The Bonferroni adjusted level of significance was 0.017 (0.05 divided by the 3 pairs). No statistically significant differences were found between formaldehyde concentrations during transportation of cadavers and dissected cadavers (p=0.100), transportation of cadavers and the control (p=0.200) or transportation of dissected cadavers and the control (p=0.200).

4.6 Formaldehyde Time-Weighted Averages

For each employee 8-hour time weighted averages were calculated. Actual transportation time was less than eight hours but remaining time of work was assumed to be similar concentrations as those during loading and unloading, since employees engaged in cremation preparation for the remainder of their shift.

All 8-hr TWA calculated concentrations (Table 4.5) were below the OSHA PEL of 0.75 ppm (0.92 mg/m^3). Results of the Wilcoxon Signed-Rank test indicate the median 8-hour time weighted average (TWA) formaldehyde concentration did not exceed the OSHA PEL (p=.0109). The short term sample concentration during dissected cadaver unloading (0.04 ppm; 0.05 mg/m^3) was below the OSHA STEL of 2.0 ppm (2.46 mg/m^3).

The ACGIH ceiling of 0.3 ppm (0.37 mg/m^3) was exceeded by both employees over Event 1 and Event 2. Time and duration of windows being open and closed and number of cadavers is summarized in Table 4.5.

Table 4.5 8-hr TWA Formaldehyde Concentrations

Sample description	**# Cadavers**	**Window open time (min)**	**Total runtime (min)**	**8-hr TWA Concentration (ppm)**
TWA personal Event 1, Employee 1	18	78	265	0.36
TWA personal, Event 2, Employee 1	24	96	444	0.41
TWA personal, Event 2, Employee 2	19	0	454	0.49

Chapter 5

Discussion

5.1 Overview

Employee exposures over Event 1 and Event 2 were below the OSHA PEL of 0.75 ppm (0.93 mg/m^3) but over the ACGIH ceiling of 0.3 ppm (0.369 mg/m^3). Employee 1 is the same person in Event 1 and Event 2 and has daily exposures to formaldehyde other than during cadaver transport. Other exposure opportunities include teaching gross anatomy lab, embalming cadavers, and completing office work such as grading papers in a room with an open door to the embalming room.

During the transport of cadavers and dissected cadavers, the 8-hr TWA for Employee 2 was approximately 16 percent higher than Employee 1 during Event 2. Employee 2 transported the same number of cadavers (11) as Employee 1 although the exposure was 12.5 percent higher (1.6 ppm compared to 1.4 ppm; 2.0 mg/m^3 compared to 1.7 mg/m^3). Employee 2 transported fewer dissected cadavers (8) than Employee 1 (13) during Event 2 but exposure levels were 44 percent greater than Employee 1 (0.23 ppm compared to 0.13 ppm; 0.27 mg/m^3 compared to 0.16 mg/m^3). Employee 1 during both events opened windows and introduced outside air for a portion of the travel time:

83 minutes during cadaver transport, and 13 minutes during dissected cadaver transport. Employee 2 kept windows closed during all transportation. No other studies were located with formaldehyde levels during cadaver transportation with which to compare the levels found in this study.

Other factors that may contribute to formaldehyde include the storage bags. It was noted the heat sealing method used for containment may be inconsistent due in part to the machinery used to create the seal. There is a very small margin between the machine not getting hot enough to create a solid seal and becoming too hot and melting the bag and destroying the seal. It was also noted the secondary zippered bags were thin and prone to being torn during loading and unloading procedures requiring physical force to lift and place bodies into position. Bags are not equipped with handles and are not intended to be used as a carrier.

There are several other medical universities in Ohio that perform embalming, loan and transport cadavers. Table 5.1 summarizes information regarding participation and transportation methods of Ohio medical universities.

Table 5.1 Cadaver Transportation Practices

School	Receive bodies	Perform Embalming	Transportation To Other Facilities
1	Self	Yes	Mortuary service
2	Self	Yes	Self
3	Self	Yes	Self
4	Self	Yes	Self
5	Mortuary Service	No	Mortuary service
6	Self	Yes	Self

Typically, a medical university receives a body donation and will either receive the body from a funeral home or will arrange to pick the body up themselves. The body is then embalmed and stored at the medical university until dissection takes place on site or the body is loaned and transported to another medical university. A body on loan may be taken and dissected for a time typically ranging from a three-month semester up to a year. After this time, the dissected body is returned to the loaning university and is prepared for cremation. Most medical universities do not perform cremation but transport the body again to a funeral home for cremation services. Inquiry into the practices of other medical institutions is to gauge the extent of common practice and the applicability of this study to local institutions.

5.2 Strengths

To date, the results of this study are the first time exposure data is to be published on formaldehyde levels during cadaver transportation. The findings demonstrate that exposure levels during cadaver and dissected cadaver transport are over the ACGIH ceiling. The collection of duplicate samples found similar results.

5.3 Limitations

The control sample during Event two had detectable levels of formaldehyde although the sample was taken away from cadavers (0.013 ppm; 0.016 mg/m^3). The sample may have been affected by off-gassing materials found in new cars. One study found a formaldehyde level in the cabin of a car one day after being delivered to be 0.0464 mg/m^3 (Yoshida et al, 2006). The control sample from this study was below this level. Also noted earlier, formaldehyde is an air pollutant sourcing from diesel vehicle

exhaust, fuel oil, and gasoline (Inci et al., 2013). Part of the control contamination may be due to large-volume vehicle traffic associated with city and highway transportation.

A statistically significant difference in the distribution of formaldehyde concentrations was found in the transportation mode groups (cadaver, dissected cadaver, control) using the Kruskal-Wallis test, but the subsequent pairwise comparisons with the Mann-Whitney U-test did not identify any significant pairs. This may be due to the small sample size.

5.4 Recommendations

Cargo vans with no barrier between the cabin and cargo space were used to transport cadavers. This creates a potential inhalation hazard to formaldehyde that may impact employees. It is recommended to use a van with a separate cargo bay thereby eliminating the chemical hazard. While keeping windows down for ventilation was noted to reduce exposure in this study, using a transport vehicle with a separate cabin and cargo area requires minimal extra cost to nearly completely eliminate formaldehyde exposure to workers.

The amount of force required to move bodies from gurneys into the rear of the cargo van was at times excessive involving full body weight and inertia to complete movements. There is a significant risk of personal strain. It is recommended to have either a hoist to assist with lifting bodies into the van or have the back of the van customized to receive trays that can easily slide from the gurney similar to the setup used in the cooled cadaver storage room. If this is not feasible, it is recommended more employees are used to move a single body decreasing the weight each worker needs to lift.

Since other schools are performing similar work, these recommendations should be communicated with other medical facilities participating in cadaver transport. Future studies may examine the extent of transportation between universities and medical facilities, seasonal exposure differences during transportation, and exposure levels using alternative transportation methods.

Chapter 6

Conclusions

A statistically significant difference in formaldehyde concentrations (p=0.044) was seen by mode of transportation (cadaver, dissected cadaver, control). The hypothesis "there is no difference in formaldehyde concentrations during transportation of cadaver transport, dissected cadaver transport and control" is rejected.

The median 8- hour TWA does not exceed the OSHA PEL of 0.75 ppm (0.92 mg/m^3) (p=0.109). The hypothesis "the median 8-hour time weighted average (TWA) formaldehyde concentration, obtained during transportation of cadavers and dissected cadavers including loading and unloading, does not exceed the current Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) of 0.75 ppm (0.92 mg/m^3)" failed to be rejected.

The short-term (15-minutes) sample was below the OSHA STEL of 2.0 ppm (2.46 mg/m^3). The hypothesis "a short-term sample (15-minutes), collected during unloading of dissected cadavers, does not exceed the current OSHA short term exposure limit (STEL) of 2.0 ppm (2.46 mg/m^3)" failed to be rejected.

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