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Comparison of real-time instrument use and absorbent tube method for measuring formaldehyde in working environments: A health risk assessment for gross anatomy staff

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ABSTRACT

Formaldehyde is widely used for the preservation of cadavers, exposing workers to potential risks of formaldehyde exposure in the workplace. This study compared the performance of real-time instruments (Gasmet) and absorbent tube methods in controlling formaldehyde levels in gross anatomy dissections with four working process areas. The concentrations of formaldehyde were determined over working periods ranging from 2 to 5 h. For the Gasmet results, a Monte Carlo simulation was applied in the uncertainty analysis to predict the formaldehyde concentration. Data collection involved questionnaires that included personal and work-related information. The Wilcoxon matched-pairs signed-rank test and intraclass correlation coefficients (ICC) were used to test–retest reliability between the two instruments. The results showed that the Gasmet direct reading and absorbent tube concentrations were not significantly different ($p > 0.05$) in all working areas and ICC was 0.939 indicating a highly reliable test result between the two measurements. The health-risk estimation indicated the hazard quotient and carcinogenic risk of formaldehyde. The carcinogenic risk was found to be unacceptable for all staff and processes, while the hazard quotient was found to be acceptable only in the body injection process. Future studies should employ a larger sample size and a greater number of sampling points to enhance the statistical power and precision of the results. The findings of this study can be used to improve work environments and develop strategies to reduce the risks for staff who work in gross anatomy dissections.

1. Introduction

Formaldehyde (H-CHO) is a chemical that is universally applied for the preservation of cadavers in dissection halls [11]. Formaldehyde is also used in the storage of biological samples and in the manufacturing of vehicles, explosives, plastics, resins, chemicals, and other artificial materials [25,4].

Within the framework of medical education, anatomists use human bodies to teach students, either by demonstrating prosected specimens or by student dissection [34]. Anatomy staff working in educational institutions or research settings are responsible for preserving cadavers to maintain their anatomical integrity and prevent decomposition during the study period. There are four steps in the embalming process, the first of which is the body injection process. This is the initial step in which embalming chemicals are injected into the body of the deceased individual. These chemicals, often containing formaldehyde, serve to slow down decomposition and preserve the body's anatomical structures [54]. After the injection, cadavers are placed a formaldehyde tank. The soaking process involves immersing the body in a solution of formaldehyde and typically takes more than one year to complete. The second step consists of raising the cadavers from the storage tank [44]. The third step, the body quality control process, is crucial to ensure that the preserved cadaver maintains its anatomical integrity and is suitable for educational or research purposes. Finally, the cadaveric dissection process is the final step, where the preserved cadaver is used for anatomical dissection and study by students, researchers, or medical professionals.

While working with a cadaver, the evaporation of formaldehyde can be harmful to workers via the inhalation and dermal routes. Acute and chronic inhalation exposure to formaldehyde in humans can result in

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respiratory symptoms and eye, nose, and throat irritation [53]. Moreover, formaldehyde is a genotoxic chemical that can cause squamous cancer of the nasal passages and cancer of the nasopharyngeal regions. The International Agency for Research on Cancer (IARC) has thus classified formaldehyde as a "human carcinogen" (Group 1) [39].Regarding recommended formaldehyde concentration levels in workplaces, the National Institute for Occupational Safety and Health (NIOSH) recommends an exposure limit (REL) of 0.016 ppm [41,42], while the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for formaldehyde in the workplace is 0.75 ppm, measured as an eight-hour time-weighted average (TWA) [33].

Formaldehyde concentrations can be measured using several different techniques, including the absorbent tube method (a laboratory-based method) and direct reading instruments. These standard methods for the analysis of indoor air pollution represent the best current practices for assessing and managing indoor air quality. These methods are often developed, published, and maintained by international or national standards organizations, such as the National Institute for Occupational Safety and Health (NIOSH), Occupational Safety and Health Administration (OSHA), and the U.S. Environmental Protection Agency (U.S. EPA). Such methods are widely accepted and recognized for their accuracy, consistency, and reliability. Analyzing indoor air quality is crucial for ensuring that indoor environments are safe and healthy for occupants [3]. However, these approaches still exhibit some limitations, such as analytical costs, turnaround time, and sampling migration. Measurement techniques have continued to evolve to overcome these limitations and minimize the negative effects of various applications, with new approaches including analytical testing and environmental monitoring. In this vein, real-time instrument technologies can bring several benefits, such as fast response times and low detection limits [19,43].

The aim of this study was to compare two methods (real-time instruments and absorbent tubes) for measuring formaldehyde in workplace environments and to assess the potential health risks associated with formaldehyde inhalation among anatomy laboratory workers at a Thai university. This assessment included estimating both carcinogenic (CR) and non-carcinogenic or adverse health effects (expressed as hazard quotient - HQ) risks. The findings of the study can serve as valuable information for improving work environments and developing strategies to reduce risks for anatomy staff members working in gross anatomy dissections.

2. Materials and methods

2.1. Study area

The study areas were gross anatomy dissection study rooms located on the first and ninth floors of the University Building. This gross anatomy dissection room consisted of both natural and mechanical ventilation. Four workplace air quality monitoring areas were differentiated based on the four working processes as follow:

Process 1: Body injection process as shown in Fig. 1

Process 2: Cadavers raising process from a storage tank as shown in Fig. 2

Process 3: Body quality control process as shown in Fig. 3

Process 4: Cadaveric dissection process as shown in Fig. 4

3. Study design and participants

A cross-sectional study was conducted between July 2023 and October 2023, which was carried out with three staff participants who worked on all processes of gross anatomy dissection. The recruitment process was based on the inclusion criteria: aged between 18 and 60 years old, proficient in Thai communication, with a minimum of one year of experience as gross anatomy staff and engaged in work activities that involve potential exposure to formaldehyde and exclusion criteria: staff who has chronic respiratory conditions such as asthma, lung cancer, chronic obstructive pulmonary disease (COPD).

Fig. 1. Body Injection Process: Formaldehyde is injected from a closed container tank.

Fig. 2. Cadaver Raising Process: Cadavers are raised from a storage tank containing approximately 7–10 bodies immersed in concentrated formaldehyde solution.

4. Data collection and instruments

4.1. Questionnaire

A questionnaire was administered through face-to-face interviews with all participants. General information and health symptoms related to formaldehyde exposure during gross anatomy dissection (i.e., symptoms involving the skin, eyes, and respiratory and central nervous systems) were assessed via the questionnaires. The questionnaire was developed and adapted from previous studies [26,4,31,40,6] by the researchers and was approved by three experts before data collection with validity value came from Index of Item-Objective Congruence (IOC) between 0.7 and 1.00.

4.2. Air sampling Instruments

Two kinds of air sampling instruments were used for the

Fig. 3. Body Quality Control: Cadavers are prepared for medical student studies and placed on designated study stations.

Fig. 4. Cadaveric Dissection Process: Medical students perform dissections on cadavers using dissection equipment to study muscles and various organ systems.

formaldehyde sampling and analysis.

1. Direct Reading Instrument
   A Gasmet GT5000 Terra FTIR Gas Analyzer was used to determine formaldehyde concentrations in the workplace areas, utilizing the Fourier transform infrared (FTIR) technique in accordance with the recommended standard method (NIOSH 3800). This device can analyze up to 50 gas compounds within 120 s. The lowest detection limit (LDL) for formaldehyde, using Calcmet Analysis STD Software, is 0.043 ppm, with a detection range up to 50 ppm (GT5000 Terra FTIR Gas Analyzer, Gasmet Technologies Oy, Helsinki, Finland). The direct reading instrument was placed in the worker's breathing zone, and samples were collected throughout the entire work period for each process. To quantify samples collected every half working time period (hr) at one location (site) in the gross laboratory according to the data quality objective and quality control requirements [41].
2. *Absorbent Tube*

The absorbent tube method (NIOSH 2541) was employed for formaldehyde sampling and analysis [40]. A personal sampling pump, the SKC 224-PCXR8 (SKC, Dorset, UK), with a representative sample of 10 % 2-hydroxymethyl piperidine on an XAD-2, 120 mg/60 mg tube, was calibrated to obtain a flow rate of 0.1 L/min. The sampler equipment was placed in the worker's breathing zone. Air samples were collected throughout the duration of the worker's task. Recalibration was performed immediately after the air sampling ended, and the average of the flow rates before and after air collection was used for concentration calculation, based on NIOSH 2541. The samples were then capped and packed for shipment to the laboratory, where they were stored in the refrigerator at 4°C until analysis within 30 days of sampling. All tube samples were shipped to the chemical laboratory at Thammasat University for analysis. The absorbent tube samples were analyzed by gas chromatography with a flame ionization detector (GC/FID; Perkin Elmer, Clarus 600 T) equipped with a DB-Wax 30 m capillary column and a 0.5 μm film thickness (Agilent Technologies, Santa Clara, CA) [2].

5. Data analysis

5.1. Uncertainty analysis

For the Gasmet samples, Monte Carlo simulations (MCS) were further conducted to examine the uncertainty in predicting the final concentrations. An MCS involves the repeated generation of random numbers from their probability distributions and the computation of the statistics of the output [23]. MCS was applied to quantify the level of formaldehyde concentration through four steps. First, the average formaldehyde concentrations were determined for each process using the Gasmet instrument's data. Then, a frequency distribution table was created that contained the average formaldehyde concentrations. In the third step, random probability numbers (ranging from 0 to 1) were generated using Microsoft Excel, considering the sampling points, concentration range (min-max values), and concentration intervals. In the final step, the average concentration of formaldehyde (ppm) was calculated.

5.2. Statistics analysis

The data from the questionnaires and a correlation analysis between the concentrations obtained by the Gasmet and absorbent tube methods were subject to statistical analyses, including descriptive statistics.In this study, formaldehyde concentrations were compared with the NIOSH REL of 0.016 ppm. Due to the non-normal distribution of the data, the Wilcoxon matched-pairs signed-ranks test was used, utilizing IBM SPSS statistics software version 17. Reliability was assessed by calculating intraclass correlation coefficients (ICC). The ICC measures the scale of measurement error by evaluating the correlation between two datasets. At a 95 % confidence interval, reliability was estimated using the following ICC value conventions: poor (ICC < 0.4), moderate ($0.4 \leq$ ICC < 0.59), good ($0.6 \leq$ ICC < 0.74), and excellent (ICC ≥ 0.75). Baeshen et al., [5].

5.3. Risk assessment

In this study, formaldehyde exposure and risk assessment were calculated by following the US.EPA guidelines [46,47,48]. Exposure concentration (EC) and exposure time (ET) values were calculated based on working conditions. The calculation was shown as follow.

$$EC = (CA \times ET \times EF \times ED)/AT$$

Where:

EC = Exposure concentration in air ($\mu g/m^3$)

CA = Formaldehyde concentration in ambient air based on air monitoring ($\mu g/m^3$)

ET = Exposure time, based on the time spent working with formaldehyde (h/day)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
AT = Average time (hr): (Exposure duration (years) x 365 d/y x 24 hr/d) Exposure duration; 25 years for the adverse health effect or 70 years for the lifetime cancer risk [10,46]

The Hazard quotient (HQ) is a value used to describe an adverse health effects assessment related to the exposure concentration (EC) which was calculated as follows. If HQ > 1, there is a potential health risk from exposure while if HQ < 1, there is likely to be an acceptable risk of a non-carcinogenic health effect.

HQ = EC/ Toxicity Value (RfC)

Where:
HQ = Hazard quotient
EC = Exposure concentration (μg/m^3)
RfC = Reference Concentration: 9.8 μg/m^3 [36,10]

For Cancer risk (CR), the likelihood of an individual developing cancer over a lifetime was calculated by using the inhalation unit risk (IUR) [45,46] as follows. The World Health Organization (WHO) has established that the acceptable range for cancer risk (CR) is between 10^{-5} and 10^{-6}, with values below this range considered acceptable. A CR value greater than 10^{-4} signifies a "definite risk," while values between 10^{-5} and 10^{-4} are regarded as a "probable risk." Values ranging from 10^{-6} to 10^{-5} are categorized as a "possible risk," and CR values under 10^{-6} are considered a "negligible risk" [18,30,55].

CR = EC x IUR

Where:
CR = Cancer risk
EC = Exposure concentration (μg/m^3)
IUR = Inhalation Unit Risk; 1.3×10^{-5} (μg/m^3) [45]

6. Results

The general profiles, and the working personal protective equipment (PPE) usage of the participants shown that there were three respondents, including one female and two males, respectively. The results showed that the participants were between 44 and 61 years old, and two respondents reported underlying diseases. All participants were involved in processes 2–4, with only two male staff members working in the body injection process. The workers had working times ranging from one to five hours, depending on the specific process.

The usage of personal protective equipment (PPE) was documented during face-to-face interviews. According to the recommended PPE for workers handling formaldehyde solution [8,32], impervious clothing is suggested. All participants reported that they usually wore impervious aprons and boots during processes 2 and 3. However, most participants used inappropriate gloves, such as rubber or fabric gloves (66.7 %), and unsuitable masks, such as filter masks. Additionally, although some participants used full facepieces, none reported using supplied-air respirator full facepieces as recommendation.

Table 1 shows the data from all four sampling working activities with respect to both the Gasmet and absorbent tube results, which were used for the comparative analysis. A total of 11 sets of measurements at 11 sampling points are presented. The concentrations of formaldehyde were determined over working periods ranging from 2 to 5 h ranged from 0.39 ppm to 7.79 ppm. The highest concentration was found in Process 2, and the lowest was found in Process 1. For Process 1, the mean concentration reading of the Gasmet was 0.43 ppm, and that of the absorbent tube was 0.41 ppm. For Process 2, the mean concentration of the Gasmet was 6.79 ppm, and the absorbent tube measurement was 6.48 ppm. The mean concentration of the Gasmet for Process 3 was 0.43 ppm, with the absorbent tube measuring 0.42 ppm. Finally, for Process 4, the mean concentration of the Gasmet was 2.56 ppm, and that of the absorbent tube was 1.62 ppm. More than 50 % of the sampling points were higher than the recommended limits established by the NIOSH for the 8-h threshold limit value-time weight average (TLV-TWA) = 0.016 ppm [41].

Table 2 shows the correlation between the two sampling methods, which was determined with the Wilcoxon matched-pairs signed-ranks test and ICC. The results show that there were no statistically significant differences between the Gasmet and absorbent tube measurements ($p > 0.05$) and the intraclass correlation coefficients (ICCs) was excellent (ICC=0.939). Compared to traditional methods like direct and indirect sampling, real-time methods offer several advantages, including the ability to provide quantitative results rapidly and with ease of use which also similar to previous study [17]. Recent advancements in technology have enabled the production of sophisticated and miniaturized sensors for various applications. These sensors typically exhibit high sensitivity, low cost, and increased portability [12,17].

Table 3 presents the health risk assessment results for the formaldehyde found in the air, which are usually quantified by an HQ < 1 and a CR > 10^{-6}. The CR of formaldehyde in all processes was within the unacceptable value range > 10^{-4}. The highest CR value was found in Process 4: Cadaveric dissection from Gasmet at CR = 0.000539 and from absorbent tube at CR = 0.000341, followed by process3: Quality control at CR = 0.000090 from Gasmet and 0.000088 from absorbent tube. The lowest CR values were found in Process 2 (CR = 0.000025). The HQ values for an adverse health effect of the formaldehyde from all air samples were analyzed, and they ranged from 0.57 to 11.85. The HQ results in this study revealed that most of processes had higher than acceptable values (HQ > 1). The highest level was found in Process 4 (HQ = 11.85: Gasmet), followed by sample from absorbent tube at HQ = 7.50. The lowest values of HQ were found in Process 2 and only this

Table 2
Differences in the concentrations of the Gasmet and absorbent tube instruments.

Sampling methods	Formaldehyde concentration (ppm) Mean ± SD	ICC (CI)	*P*-value
Gasmet Absorbent tube instruments	2.81 ± 2.87 2.40 ± 2.85	0.939 (0.774–0.984)	0.285

Table 1
Formaldehyde concentration (ppm) in real-time instruments and absorbent tube methods.

Working Process	Working time (hr)	Formaldehyde concentration (ppm)			
		Mean (SD)		TLV-TWA (min-max)	
		Gasmet	Absorbent tube	Gasmet	Absorbent tube
Process 1: Body injection	2	0.43 (0.05)	0.41 (0.35)	0.11 (0.10–0.20)	0.10 (0.04–0.16)
Process 2: Cadaver raising	5	6.79 (0.01)	6.48 (2.12)	4.24* (4.20–4.24)	4.05* (2.63–5.26)
Process 3: Body quality control	3	0.43 (0.04)	0.42 (0.01)	0.16* (0.15–0.18)	0.16* (0.15–0.16)
Process 4: Cadaveric dissection	3	2.56 (0.14)	1.62 (0.64)	0.96* (0.90–0.99)	0.61* (0.36–0.84)

Note: (*) Unacceptable level: TLV-TWA = 0.016 ppm [41,42].

Table 3
Hazard quotient (HQ) and cancer risk (CR) values for the carcinogenic and adverse health effects of formaldehyde in each process.

Process	Gasmet		Absorbent tube instruments	
	CR	HQ	CR	HQ
Process 1 Body injection	0.000052*	1.15*	0.000050*	1.09*
Process 2 Raising cadavers from a storage tank	0.000027*	0.58	0.000025*	0.57
Process 3 Quality control	0.000090*	1.97*	0.000088*	1.93*
Process 4 Cadaveric dissection	0.000539*	11.85*	0.000341*	7.50*

Note: (*) Unacceptable level.

process that the HQ were acceptable level.

7. Discussion

The study population consisted of three workers with an average age of 51 years, and the range of work experience in gross anatomy ranged from five to more than 15 years. The workers had exposure times ranging from two hour to up to five hours in each working area where formaldehyde was used. The working processes of the anatomy staff had different formaldehyde concentrations. The lowest concentration of formaldehyde was found in Process 1 (body injection) due to the source of the formaldehyde concentration coming from the formaldehyde tank used for the injection, which was a closed container. Thus, it was more difficult for formaldehyde to evaporate into the working atmosphere in this process compared to the others. In contrast, in Process 2 (raising cadavers from a storage tank), the highest concentration of formaldehyde was found.

Regarding work activities, individuals in this facility worked with the cadavers in the tanks with concentrated formaldehyde for a period of 1–2 years. In this study, each tank contained approximately 7–10 bodies. A total of 28 bodies were in this process 2. Hence, a high concentration of formaldehyde was generated through the evaporation of the large volume of formalin solution in the cadaver's tanks. This area was subject to natural ventilation, which could have contributed to the high concentration of formaldehyde [28]. In Process 3, the formaldehyde concentration was attributed to the source from cadavers being prepared for medical students' studies. During this step, as the cadavers were placed on the study station and prepared over time, formaldehyde had the opportunity to evaporate and disperse through natural ventilation. Throughout the gross anatomy lab session, one cadaver was studied, and staff attended to the cadavers 1–2 times per week until the session concluded. Consequently, this resulted in a less concentrated form of formaldehyde compared to the other processes. In Process 4, the source of the formaldehyde concentration was the 28 cadavers used as teaching materials for medical students. The educational process involved the use of dissection equipment by medical students to study muscles and various organ systems, leading to increased formaldehyde evaporation from cadavers.

Several studies have investigated formaldehyde in the workplace, especially in indoor working environments. In our study, the working period among gross anatomy staff ranged from 2 to 5 h. While the 8-hour Occupational Exposure Limit (OEL) is a common benchmark, formaldehyde concentrations were determined over this 2- to 5-h range, which can provide a reliable estimate of compliance when assessing exposure profiles within the context of the actual working hours [13]. Formaldehyde concentration levels were measured in both the working area and the personal breathing zone of laboratory workers. Our study findings align with previous cross-sectional investigations conducted in university laboratories. Notably, this study demonstrated that formaldehyde concentrations in most working areas exceeded the TLV-TWA, consistent with previous research that reported elevated personal exposure levels and area concentrations surpassing occupational exposure limits [16]. Other factors that may impact the formaldehyde concentration in the working environment should also be considered, such as humidity and temperature. This potential correlation aligns with previous research on the relationship between indoor air quality and perceived air quality, as discussed by Pei et al. [35]. In their study, the consideration of relative humidity was crucial, as the anatomy laboratory's conditions were consistent with those found in other research on indoor air quality [35]. Another study among medical students at Thai University found a significant relationship between relative humidity and skin symptoms. Other factors, including the concentration of formaldehyde, have also been shown to affect skin symptoms and respiratory illness [26,31]. In terms of the health effects of formaldehyde exposure, another study revealed that medical students reported fatigue and eye pain during anatomy classes [27]. Likewise, an earlier study measuring formaldehyde concentrations in anatomy laboratories found that students experienced abnormalities in the eyes, nose, pharynx, skin, and headaches [38].

In the present study, the different methods used to measure concentrations of formaldehyde, which included absorbent tube and direct reading tools (Gasmet), revealed no differences in the results ($p > 0.05$). The intraclass correlation coefficient (ICC) was excellent (ICC=0.939), indicating a highly reliable test result between the two measurements. While comparisons between absorbent tubes and Gasmet have been limited, other studies have investigated the standard method and direct reading instruments. They found that the performance of the PPM Technology Formaldehyde (direct reading instrument) was not significantly different from the NIOSH 2016 standard method [21]. Moreover, the results were consistent with those of a comparative study of global greenhouse gases (GHGs) using an FTIR analyzer and a gas chromatography (GC) analyzer, in which FTIR testing was found to be reliable compared to a GC and absorbent device [52]. This suggests that direct reading instruments can be used to assess air concentrations in the workplace.

Since gross anatomy staff can be vulnerable to increased health risks through the inhalation route, this study explored the CR and HQ for each staff member. The results of the study indicated that a total of three anatomy staff members were at risk of developing cancer from exposure to formaldehyde, as the formaldehyde concentration in the working area exceeded the acceptable level ($CR > 1 \times 10^{-4}$) ([18,30,49,55]). The average risk of developing cancer in this study fell within the range of 2.50×10^{-5} to 5.3×10^{-4}. This finding is consistent with research on formaldehyde exposure among cadaver dissecting and treatment personnel, where the average exposure over an eight-hour working period (TWA) resulted in an unacceptable level of CR. The average risk of cancer reported in that study was $5.05 \times 10^{-4} \pm 4.88 \times 10^{-4}$ ([7].). For adverse health effects, this study revealed that Processes 1, 3, and 4 exhibited a risk level in the range of 1.09–11.85, falling within the unacceptable range ($HQ > 1$). Furthermore, the average exposure over an eight-hour working period (TWA) in Processes 2, 3, and 4 resulted in an unacceptable level of HQ. This finding aligns with research studying risk assessment from exposure to formaldehyde through breathing by personnel working within anatomy rooms. For instance, one study demonstrated that the risk values for non-carcinogenic effects (HQ) varied depending on the teaching process and the specific organ being dissected for study, with the HQ ranging from 0.02 to 11.44 [10]. However, when considering an $HQ > 0.5$ at the occupational health action level, the results showed that all processes exceeded the acceptable level. This finding is consistent with a previous study that reported adverse health effects among workers in mortuary laboratories [10]. As the results demonstrate, three work processes exhibited TLV-TWA levels exceeding acceptable limits, and all processes presented at least one unacceptable risk assessment. Therefore, strategies to mitigate these unacceptable risk levels should be implemented. These strategies should include engineering controls such as enhanced ventilation systems [37,9]. Additionally, organizational changes, such as educating workers about safe work practices and involving them in risk management strategies, can significantly enhance compliance and awareness [14,37].

The personal circumstances and working conditions of anatomy staff have been found to have a significant influence on the health risks associated with formaldehyde exposure [1]. Consequently, in the present study, it was evident that the anatomy staff may have been exposed to formaldehyde, even outside of their work conditions. The study's results revealed that two participants had conditions including thalassemia, herniated-disk disease, and hypercholesterolemia. Additionally, 66.7 % of the anatomy staff were found to have current smoking habits, indicating an increased health risk [29]. A previous study showed that formaldehyde is a major oxidation byproduct of combustion processes, including smoking, with detectable concentrations ranging from 10 ug to over 100 μg/cigarette [20]. Another study indicated that alcohol can contain approximately 0.27 mg/liter of formaldehyde [22].

The present study found that all anatomy staff consistently wore aprons and boots, exhibiting 100 % compliance with this protective measure. However, the use of inappropriate masks, such as chemical filter masks designed primarily for particulate protection, was reported. Although some participants used full facepieces, none reported using supplied-air respirator full facepieces as recommended by the Canadian Centre for Occupational Health and Safety [8] and the Occupational Safety and Health Administration [32]. This often led to removing the equipment after a while, resulting in incomplete protection throughout the entire working process. Additionally, 66.7 % of the staff wore medical or rubber gloves each time they worked, which are not recommended for handling formaldehyde solutions [8]. Wearing PPE is crucial as it can significantly reduce exposure to formaldehyde, which anatomy staff may come into contact through their skin and the conjunctiva of their eyes [15]. The results from a previous study showed that there was a significant relationship between respiratory conditions and the use of respiratory PPE in the laboratory ($p = 0.01$) [50]. Consequently, PPE should be provided, and air formaldehyde controls should be implemented to increase the safety of anatomy staff [24]. This comprehensive use of PPE aims to further prevent exposure to formaldehyde during work processes [51]. To enhance protection further, it is recommended that anatomy staff utilize impervious clothing, boots, and chemical protective masks and goggles. Future studies should incorporate metrics to evaluate the effectiveness of PPE in mitigating exposure.

8. Conclusions

A comparison of real-time instruments and the absorbent tube method for measuring formaldehyde concentrations in workplace environments revealed no significant difference between the two methods. This study aimed to evaluate the accuracy of formaldehyde concentration assessments by comparing these two measurement techniques. The results demonstrate that both methods yielded comparable results. The concentration of formaldehyde was found to be based on specific working conditions, as different work processes involve distinct sources of formaldehyde. For instance, factors such as the number of cadavers used, the presence of pickling tanks, and the locations where formaldehyde was stored all contributed to varying concentrations of formaldehyde in the environment. The health risk assessment of the anatomy staff in terms of both CR and HQ from exposure to formaldehyde found that the HQ of participants ranged from 0.57 to 11.85, and only Process 2 had an HQ at an acceptable level, while the CR was found to be in the range of 0.000025–0.000539, with no process having an acceptable level of risk. Generally, the literature shows that PPE usage while working and the personal behaviors of smoking and drinking alcohol may increase the health risk from exposure to formaldehyde.

Additionally, health surveillance for workers is crucial, with data limited to only three workers in the gross anatomy laboratory. Consequently, the results may not be fully representative and generalizable due to the small sample size. Future studies should include a larger sample size to enhance the statistical power and improve the generalizability of the findings. Moreover, increase the number of sampling points can enhance result precision. To confirm formaldehyde exposure among workers, future studies should include biomarker assessments of formaldehyde metabolites. This study primarily focused on measuring the working environment, however, ventilation measurements were not conducted due to limitations in the existing ventilation system within the study area. Future studies should include comprehensive ventilation assessments to better understand the impact of formaldehyde exposure. While complete elimination or substitution of formaldehyde may not be feasible, implementing improved ventilation systems and reducing exposure times can significantly improve working conditions for gross anatomy staff. Lastly, the use of proper personal protective equipment (PPE) such as impervious gloves, aprons, boots, chemical safety goggles, and full-facepiece supplied-air respirators is essential to minimize formaldehyde exposure.

Ethical considerations

Informed consent was obtained from all participants involved in the study and all participants provided their written consent before data collection, indicating their willingness to participate. Ethical approval to conduct this study was received from the Human Research Ethics Committee, Thammasat University (Science) (HREC-TUSc), COA No. 055/2566.

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CRediT authorship contribution statement

Chalermchai Chaikittiporn: Writing – review & editing. **Arroon Ketsakorn:** Writing – review & editing, Data curation, Conceptualization. **Nontiya Homkham:** Writing – review & editing, Formal analysis. **Phanpina Soonklang:** Writing – original draft, Investigation, Data curation, Conceptualization. **Saowanee Norkaew:** Writing – review & editing, Writing – original draft, Supervision, Funding acquisition, Data curation, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

AI and AI-assisted technologies should not be listed as an author or co-author or be cited as an author. Authorship implies responsibilities and tasks that can only be attributed to and performed by humans.

Declaration of Competing Interest

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

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Data availability

Data will be made available on request.

References

[1] D. Adamović, Z. Čepić, S. Adamović, M. Stošić, B. Obrovski, S. Morača, M. Vojinović Miloradov, Occupational exposure to formaldehyde and cancer risk assessment in an anatomy laboratory, Int. J. Environ. Res. Public Health 18 (21) (2021) 11198, https://doi.org/10.3390/ijerph182111198.
[2] Agilent Technologies. (2023). *Gas Chromatography (GC) Solutions*. Retrieved 2022 Oct 29 from ⟨https://www.agilent.com/en/product/gas-chromatography⟩.
[3] Announcement from the Department of Labor Protection and Welfare, 2023 Oct 5 (2016). ⟨https://www.mol.go.th/wp-content/uploads/sites/2/2018/08/150.pdf⟩.
[4] W.-Y. Aung, H. Sakamoto, A. Sato, E.-E.-P.-N. Yi, Z.-L. Thein, M.-S. Nwe, N. Shein, H. Linn, S. Uchiyama, N. Kunugita, Indoor formaldehyde concentration, personal formaldehyde exposure and clinical symptoms during anatomy dissection sessions, University of Medicine 1, Yangon, Int. J. Environ. Res. Public Health 18 (2) (2021) 712, https://doi.org/10.3390/ijerph18020712.
[5] A. Baeshen, P.O. Wyss, A. Henning, R.L. O'Gorman, M. Piccirelli, S. Kollias, L. Michels, Test–retest reliability of the brain metabolites GABA and Glx with JPRESS, PRESS, and MEGA-PRESS MRS sequences in vivo at 3T, J. Magn. Reson. Imaging 51 (4) (2020) 1181–1191.
[6] L. Bentum, L.K. Brobbey, R.O. Adjei, P. Osei-Tutu, Awareness of occupational hazards, and attitudes and practices towards the use of personal protective equipment among informal woodworkers: the case of the Sokoban Wood Village in Ghana, Int. J. Occup. Saf. Ergon. 28 (3) (2022) 1690–1698, https://doi.org/10.1080/10803548.2021.1928390.
[7] V. Boonyayothin, Cancer risk assessment of formaldehyde exposurevia inhalation among autopsy staffs, R. Thai Army Med. J. 71 (2018) https://doi.org/10.31557%2FAPJCP.2020.21.5.1303.
[8] Canadian Centre for Occupational Health and Safety (CCOHS). (2023). *Chemical Profiles: Formaldehyde Solution* ⟨https://www.ccohs.ca/oshanswers/chemicals/chem_profiles/formaldehyde.html#on-this-page-hdr⟩.
[9] F. Castellani, M. Vitali, A. Antonucci, L. Cofone, G. D'Ancona, I. Pindinello, G. Buomprisco, M. Petyx, C.L. Ursini, C. Protano, Effective mitigation strategies for reducing workers' exposure to formaldehyde: a systematic review, Air Qual. Atmosphere Health 17 (4) (2024) 877–890.
[10] S. Chaiklieng, U. Tongsantia, H.N. Autrup, Risk assessment of inhalation exposure to formaldehyde among workers in medical laboratories, Asia-Pac. J. Sci. Technol. 26 (2021) 4.
[11] N. Chhabra, Long term preservation of cadavers: substitution of formalin with phenoxyethanol: need of the hour, Int. J. Anat. Res. 8 (2.3) (2020) 7554–7560, https://doi.org/10.16965/ijar.2020.158.
[12] P.-R. Chung, C.-T. Tzeng, M.-T. Ke, C.-Y. Lee, Formaldehyde gas sensors: a review, Sensors 13 (4) (2013) 4468–4484.
[13] F. Clerc, R. Vincent, Assessment of occupational exposure to chemicals by air sampling for comparison with limit values: the influence of sampling strategy, Ann. Occup. Hyg. 58 (4) (2014) 437–449.
[14] G. d'Ettorre, A. Caroli, M. Mazzotta, Minimizing formaldehyde exposure in a hospital pathology laboratory, Work 69 (1) (2021) 209–213.
[15] G. d'Ettorre, M. Criscuolo, M. Mazzotta, Managing formaldehyde indoor pollution in anatomy pathology departments, Work 56 (3) (2017) 397–402, https://doi.org/10.3233/wor-172505.
[16] A. Dehdashti, P. 1.09 Risk assessment of exposure to formaldehyde in university laboratories, Occup. Environ. Med. 76 (1) (2019) A80.
[17] S. Dugheri, D. Massi, N. Mucci, G. Marrubini, G. Cappelli, A. Speltini, M. C. Bonferoni, G. Arcangeli, Exposure to airborne formaldehyde: sampling and analytical methods—a review, Trends Environ. Anal. Chem. 29 (2021) e00116.
[18] P. Foroughi, F. Golbabaei, M. Sadeghi-Yarandi, M. Yaseri, M. Fooladi, S. Kalantary, Occupational exposure, carcinogenic and non-carcinogenic risk assessment of formaldehyde in the pathology labs of hospitals in Iran, Sci. Rep. 14 (1) (2024) 12006.
[19] Gasmet Technologies Oy (2020). *Gasmet dx4040 brochure spread* Retrieved 2024 Jan 21 from ⟨https://pdf.directindustry.com/pdf/gasmet-technologies/gasmet-dx4040-brochure-spread/25815-737038-_2.html⟩.
[20] T. Godish, Formaldehyde exposures from tobacco smoke: a review, Am. J. Public Health 79 (8) (1989) 1044–1045.
[21] D.V. Hirst, M.G. Gressel, W.D. Flanders, Short-term monitoring of formaldehyde: comparison of two direct-reading instruments to a laboratory-based method, J. Occup. Environ. Hyg. 8 (6) (2011) 357–363, https://doi.org/10.1080/15459624.2011.578499.
[22] J.A. Jendral, Y.B. Monakhova, D.W. Lachenmeier, Formaldehyde in alcoholic beverages: large chemical survey using purpald screening followed by chromotropic acid spectrophotometry with multivariate curve resolution, Int. J. Anal. Chem. 2011 (2011), https://doi.org/10.1155/2011/797604.
[23] Johansen, A.M., Evers, Ludger (2010). *Monte carlo methods* (University of bristol Ed.) ⟨https://people.bordeaux.inria.fr/pierre.delmoral/teaching-notes-levers-johansen.pdf⟩.
[24] B. Joob, V. Wiwanitkit, Formaldehyde level in anatomy laboratory teaching room and risk for cancer, Workplace Health Saf. 64 (4) (2016), https://doi.org/10.1177/216507991560787, 132-132.
[25] D.A. Kaden, C. Mandin, G.D. Nielsen, P. Wolkoff, Formaldehyde. WHO Guidelines for indoor air quality: selected pollutants, World Health Organization, 2010.
[26] A. Ketsakorn, S. Norkaew, K. Changkaew, C. Chaikittiporn, V. Su-angkavatin, P. Thammabut, R. Chaiyadej, An artificial neural network prediction model of respiratory illness among medical students during gross anatomy dissection classes, EnvironmentAsia 14 (3) (2021).
[27] K. Lakchayapakorn, P. Watchalayarn, Formaldehyde exposure of medical students and instructors and clinical symptoms during gross anatomy laboratory in Thammasat University, J. Med. Assoc. Thai 93 (7) (2010). S92-98.
[28] M. Lv, S. Liu, Q. Cao, T. Zhang, J. Liu, Influence of Ventilation on Indoor Air Quality, in: K. Yinping Zhang Philip, Hopke Corinne Mandin (Eds.), Handbook of Indoor Air Quality, Springer, 2022, pp. 1637–1673.
[29] A. Mahboubi, A. Koushik, J. Siemiatycki, J. Lavoué, M.-C. Rousseau, Assessment of the effect of occupational exposure to formaldehyde on the risk of lung cancer in two Canadian population-based case—control studies, Scand. J. Work, Environ. Health 39 (4) (2013) 401–410, https://doi.org/10.5271/sjweh.3344.
[30] G. Miller, P. Fortney, T. Lantos, M. Thompson, N. Pelosi, A. Eshoo, B. Lee, L. Woolsey, Exposure to hazardous air pollutants in the San Francisco Bay area, Atmos. Environ. 19 (1999) 425–432.
[31] S. Norkaew, P. Thammabut, R. Chaiyadej, K. Changkaew, N. Yamasamit, A. Ketsakorn, Indoor air quality and its associations with skin related syndrome among medical students during gross anatomy dissection, J. Sci. Technol. MSU 40 (2) (2021).
[32] Occupational Safety and Health Administration (OSHA). (2011). *formaldehyde-factsheet* ⟨https://www.osha.gov/sites/default/files/publications/formaldehyde-factsheet.pdf⟩.
[33] OSHA. (2011). *Formaldehyde*. us. department of labor. Retrieved 2022 Jun 12 from ⟨https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.1048⟩.
[34] W. Panunto, The analytical trend of body donation for study and research at faculty of medicine, Thammasat University, Thammasat Med. J. 18 (4) (2018) 619–625.
[35] J. Pei, M. Qu, L. Sun, X. Wang, Y. Yin, The relationship between indoor air quality (IAQ) and perceived air quality (PAQ)–a review and case analysis of Chinese residential environment, Energy Built Environ. (2022), https://doi.org/10.1016/j.enbenv.2022.09.005.
[36] M. Pokorski, Pulmonary care and clinical medicine, Springer, 2017.
[37] P.T. Scheepers, M.H. Graumans, G. Beckmann, M. Van Dael, R.B. Anzion, M. Melissen, N. Pinckaers, L. Van Wel, L.M. De Werdt, V. Gelsing, Changes in work practices for safe use of formaldehyde in a university-based anatomy teaching and research facility, Int. J. Environ. Res. Public Health 15 (9) (2018) 2049.
[38] K. Tanaka, K. Nishiyama, H. Yaginuma, A. Sasaki, T. Maeda, S. Kaneko, T. Onami, M. Tanaka, Formaldehyde exposure levels and exposure control measures during an anatomy dissecting course, Kaibogaku zasshi. J. Anat. 78 (2) (2003) 43–51.
[39] The International Agency for Research on Cancer, Formaldehyde, 2-butoxyethanol and 1-tert-butoxypropan-2-ol, IARC monographs on the evaluation of carcinogenic risks to humans 88 (2006) 1.
[40] The National Institute for Occupational Safety and Health (NIOSH), FORMALDEHYDE by GC: Method 2541, Manual of Analytical Methods: The National Institute for Occupational Safety and Health (NIOSH) (1994).
[41] The National Institute for Occupational Safety and Health (NIOSH). (2014). *NIOSH Manual of Analytical Methods (NMAM) 5th Edition* ⟨https://www.cdc.gov/niosh/nmam/default.html⟩.
[42] The National Institute for Occupational Safety and Health (NIOSH). ORGANIC AND INORGANIC GASES by Extractive FTIR Spectrometry: 3800, The National Institute for Occupational Safety and Health (NIOSH, 2016.
[43] Theyab, N.B., Al-Jameel, H.A.E., & Almuhanna, R.R. (2021). Impact of Traffic Flow on Pollution at Urban Intersections. Journal of Physics: Conference Series,
[44] T. Topp, T. Müller, S. Huss, P.H. Kann, E. Weihe, S. Ruchholtz, R.P. Zettl, Embalmed and fresh frozen human bones in orthopedic cadaveric studies: which bone is authentic and feasible? A mechanical study, Acta Orthop. 83 (5) (2012) 543–547, https://doi.org/10.3109/17453674.2012.727079.
[45] U.S. Environmental Protection Agency. (1991). *Integrated Risk Information System (IRIS): Formaldehyde*; *CASRN 50-00-0* ⟨https://cfpub.epa.gov/ncea/iris/iris_documents/documents/subst/0419_summary.pdf#nameddest=woe⟩.
[46] U.S. Environmental Protection Agency. (2009). Risk assessment guidance for superfund volume I: human health evaluation manual (Part F, supplemental guidance for inhalation risk assessment) ⟨https://www.epa.gov/sites/default/files/2015-09/documents/partf_200901_final.pdf⟩.
[47] U.S. Environmental Protection Agency. (2011). *Exposure Factors Handbook 2011 Edition (Final Report)* (EPA/600/R-09/052F, 2011 ed.). U.S. Environmental Protection Agency.
[48] U.S. Environmental Protection Agency. (2019). *Guidelines for Human Exposure Assessment* (EPA/100/B-19/001 ed.). U.S. Environmental Protection Agency,.
[49] U.S. Environmental Protection Agency. (2022). *IRIS Toxicological Review of Formaldehyde-Inhalation (External Review Draft, 2022)* (EPA/635/R-22/039, 2022 ed.). U.S. Environmental Protection Agency.
[50] A.C. Ufelle, A.G. Lee, M. Kimberly Forrest, Health effects and factors affecting formaldehyde exposure among students in a cadaver laboratory, J. Environ. Health 84 (6) (2022) 14–21.
[51] UNL Environmental Health and Safety. (2002). *TOXICOLOGY AND EXPOSURE GUIDELINES*. University of Nebraska–Lincoln. Retrieved 2023 May 11 from ⟨https://ehs.unl.edu/documents/tox_exposure_guidelines.pdf⟩.
[52] H. Warlo, K. Machacova, N. Nordstrom, M. Maier, T. Laemmel, A. Roos, H. Schack-Kirchner, Comparison of portable devices for sub-ambient concentration measurements of methane (CH4) and nitrous oxide (N2O) in soil research, Int. J. Environ. Anal. Chem. 98 (11) (2018) 1030–1037, https://doi.org/10.1080/03067319.2018.1517871.

[53] World Health Organization (2010). *WHO guidelines for indoor air quality: selected pollutants*. World Health Organization. Regional Office for Europe.

[54] S.H. Ya'acob, A.J. Suis, N. Awang, M. Sahani, Exposure assessment of formaldehyde and its symptoms among anatomy laboratory workers and medical students, Asian J. Appl. Sci. 6 (2013) 50–55, https://doi.org/10.3923/ajaps.2013.50.55.

[55] Z. Zhang, X. Yan, F. Gao, P. Thai, H. Wang, D. Chen, L. Zhou, D. Gong, Q. Li, L. Morawska, Emission and health risk assessment of volatile organic compounds in various processes of a petroleum refinery in the Pearl River Delta, China, Environ. Pollut. 238 (2018) 452–461.