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Video Exposure Assessments Demonstrate Excessive Laboratory Formaldehyde Exposures

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Video exposure assessments were conducted in a comparative anatomy laboratory using formaldehyde-preserved sharks and cats. Work in the facility using time-integrated samplers indicated personal and area concentrations generally below the current OSHA permissible exposure limit. However, complaints about room air quality were frequent and routine. Using a photoionization detector with an integral data logger, total ionizables present were sampled as a surrogate for formaldehyde. After synchronizing time tracks from the datalogger concentrations with simultaneously created videotapes of laboratory tasks, composite video exposure overlays were generated. Use of this video exposure method revealed very short-lived, excessively high peak exposure events, whereas conventional time-weighted averages indicated the majority (30/32) of personal exposures were below the OSHA limit of 0.75 ppm. These legally acceptable exposure levels were associated with self-reported symptoms of burning nose and eyes and eye irritation. Thus, transient peak formaldehyde concentrations not detected by longer term averaging studies could be responsible for the health effects reported. The video exposure monitoring method demonstrated that close dissection work, opening peritoneal cavities, and specimen selection activities were most likely the causes of elevated student exposures. Teaching assistants' exposures were the highest, exceeding OSHA limits on several occasions. The utility of the video monitoring method for conducting enhanced, critical task exposure assessments is discussed.

Keywords Formaldehyde, Laboratory, Video Exposure Assessment, Anatomy, PID

Although official estimates are lacking, the number of U.S. students annually exposed to formaldehyde in undergraduate and professional school anatomy courses can reasonably be estimated in the tens of thousands. Exposures in such settings result from specimen selection, dissection, examination, testing, and disposal. Though modest inroads have been made in multimedia instruction on this topic serving to reduce the total number of hours spent in laboratory instruction, accredited programs continue to rely on real-time laboratory instruction. Anecdotal information indicates that despite organizational compliance with various OSHA-styled hazard communication training requirements, students and staff alike continue to work in environments contaminated with irritating levels of formaldehyde. This article describes a video exposure assessment method in which real-time monitoring instrument outputs are digitally superimposed on videotaped animal dissection tasks. Through this technique those specific job elements that contribute the most to exposures can be identified. Such information can in turn be utilized in an attempt to identify realistic interventions that will lower exposures both in animal anatomy as well as human anatomy laboratories.

PAST STUDIES OF FORMALDEHYDE EXPOSURE IN LABORATORIES

Past studies (Table I) demonstrate that modern anatomy laboratory exposures to formaldehyde are consistently in the 0.1–3 ppm range,[1–4] despite an OSHA permissible exposure limit (PEL) of 0.75 ppm,[5] a NIOSH-recommended exposure level (REL) of 0.016 ppm,[6] and an ACGIH® ceiling threshold limit value (TLV®) of 0.3 ppm.[7] A majority of studies examining irritant health effects from such exposures have produced positive findings (Table I, Comments). Various authors have described major causes of formaldehyde exposures in the teaching laboratory and have identified a number of specific exposure risk factors and potentially effective controls.[8–12] However, a legitimate limitation to even the most meticulously performed study has been the necessary reliance on variable length time-weighted assessments to estimate exposure.

For example, several early studies examined formaldehyde exposures in anatomy operations by means of 1–2 hour sampling runs.[13–15] Results of this work generated listings of exposures

TABLE I
Chronological summary of previous studies of formaldehyde levels in laboratories

Author, year	Personal range (ppm)	n	Area range (ppm)	n	Sampling period (minutes)	Comments
Skisak, 1983	0.3–2.63	54	<1.0	10	60	Half of BZ[A] samples in 0.6–1.0 range
Perkins and Kimbrough, 1985	0.24–6.77	68	0.18–1.29	15	60–120	BZ mean = 1.69; area mean = 0.5
Korky et al., 1987	N/A	—	<1.0–16.5	6	60	Area mean = 7.02
Chia et al., 1992	0.41–1.20	14	0.40–0.60	14	150	BZ mean = 0.74; area mean = 0.5; irritation reported[B]
Kriebel et al., 1993	0.49–0.93	24	N/A	—	90	BZ mean = 0.73; irritation reported
Akbar-Khanzadeh et al., 1994	0.07–2.94	32	1.00, 2.30	2	10–300	BZ mean = 1.24; area mean = 1.65; irritation reported
Wantke et al., 1996	N/A	—	0.06–0.22	17	180	Area mean = 0.12; irritation reported
Kim and Cho, 1999	N/A	—	0.16–9.16	48	60–120	Area mean = 3.00; irritation reported
Wantke et al., 2000	N/A	—	0.11–0.33	N/A	180	Area mean = 0.22; irritation reported
Kriebel et al., 2001	N/A	—	<0.05–10.91	[C]	116	Area mean = 0.70; irritation reported
Keil et al., 2001	N/A	—	0.52–1.48	50	180–240	—

[A]BZ = Breathing Zone.
[B]Symptoms of irritation were described in study subjects exposed to the levels of formaldehyde reported.
[C]A real-time instrument was used to collect 3,566 12-minute samples.

with respect to various contributing factors or laboratory role (e.g., instructor versus student). Area samples, as opposed to personal, were frequently studied. In a 1985 study,[(14)] 36 percent of instructors and 31 percent of students exceeded 1 ppm levels, and the majority of exposures would not be in compliance with the current OSHA limit.

Chia[(12)] monitored personal formaldehyde exposures over a 2.5 hour dissection time. Results showed concentrations of formaldehyde that fluctuated greatly, depending primarily on the site of the cadaver being dissected. Concentrations were greatest when cadaver bags were first opened and when the students were dissecting the body cavity or deep structures. Akbar-Khanzadeh et al.[(11)] also used personal samplers on students to obtain multiple hour time-weighted averages (TWA) in personal breathing zones. Over the course of five weeks, exposures ranged from 0.07 to 2.94 TWA-ppm.

As recently as 1999, Kim et al.[(3)] studied 1–2 hour area formaldehyde concentrations in a Korean dissection laboratory. The results yielded a range of exposures from 0.16–9.16 TWA-ppm. These levels were higher than even the present OSHA short-term exposure limit (STEL) of 2 ppm measured for 15 minutes.[(5)] The authors noted that low doses of formaldehyde (i.e., 0.4 ppm) caused irritation.

There is evidence that high peak exposures may contribute significantly to the development of health symptoms in exposed instructors or students. In 1993, Kriebel et al.[(16)] attempted to correlate formaldehyde exposures to self-reported symptoms of formaldehyde exposure. Symptoms included eye, nose, and throat irritation; coughing; sneezing; and breathing difficulties. The highest short-term (12-minute interval) exposure noted, 10.91 ppm, was over five times the current OSHA STEL. Results also showed a geometric mean participant exposure of 0.73 TWA-ppm for approximately 3 hours per week. Recent work by Kriebel et al.[(17)] demonstrated that in the body cavity of the cadavers, formaldehyde levels peaked at 4.3 ppm, while time-weighted personal samples in the breathing zone reflected comparatively low values of 0.49–0.93 ppm. Thus, even with average TWA personal exposures of less than 1 ppm, high transient peak concentrations have been associated with health symptoms.

One plausible explanation for the appearance of irritant effects in atmospheres containing only low TWA exposures is that TWA assessment methodology using conventional periods (e.g., 15 minutes) is an incomplete approach to anatomy laboratory formaldehyde exposure assessment. Limitations of such an approach are analogous to the use of area sampling data for estimating personal exposures in such environments. For example, the lack of relevance between area and personal formaldehyde samples is quite apparent in the work of Pabst.[(9)] In his paper summarizing observable health hazards of formaldehyde, air concentrations in the breathing zone ranged up to five times higher than room air samples.

Korky et al.[(15)] found area samples almost an order of magnitude lower in the rear of a biology lab as compared with the actual teaching areas (i.e., 1.9–2.6 ppm versus 7.0–16.5 ppm, respectively). As demonstrated by these studies, formaldehyde exposures drop off rapidly with distance from the breathing zone. Thus, a technique for more precisely identifying formaldehyde concentrations in real-time, in a student's breathing zone, will give the truest estimate of total formaldehyde exposure. Irritant effects observed in the laboratory may more closely track to known toxicity data for this chemical once more accurate estimates of exposure are possible.

FORMALDEHYDE TOXICITY

Although formaldehyde has been an important preservative for more than a century,[18] its toxicology continues to be actively researched. Based on such studies, the allowable or recommended exposure limits to formaldehyde have steadily declined in the last 20 years.[5,14] Given this history and the continued finding of irritating effects at present levels of exposure, a brief summary of the currently known hazardous properties of formaldehyde is in order. A review of formaldehyde toxicity can be found in the ACGIH TLV documentation.[19]

Formaldehyde causes sensory irritation, and the eyes, nose, throat, and lungs are often irritated at OSHA-permissible concentrations. Eye irritation and lacrimation, in particular, are common complaints, with reported sensitivity from concentrations as low as 0.01 ppm in some cases.[20] Itching of the eyes, dry and sore throat, and thirst have been reported post-exposure to concentrations ranging from 0.9 to 1.66 ppm. Results from animal studies show cellular changes in the upper respiratory tract, where inhibition of mucous flow has also been seen at 0.5 ppm.[21] Long-term formaldehyde exposure is associated with cytological changes. A biopsy-based study conducted on 20 men exposed to 0.1 ppm to 1.1 ppm formaldehyde for an average of 7 years reported that 25 percent had swollen or dry nasal mucosal, loss of cilia and goblet cells, squamous metaplasia, and mild dysphasia.[22] Nasal erythema and edema has also been noted.[23] Finally, formaldehyde is considered a suspected human carcinogen, classified as group A2 by ACGIH.[7,19] 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.[24,25]

Given the emergence of new toxicology data relative to low ppm formaldehyde levels,[17] and documented health effects at current exposure limits,[20,22] the need exists for a more responsive method of quantitatively determining formaldehyde exposures. In their comprehensive evaluation of laboratory student exposures to a variety of compounds, Tan et al.[10] directly pointed to the potential utility of coupling a direct reading datalogging instrument to videotaping to identify operations causing higher exposures. The method described in the following section details efforts to develop such a video exposure assessment method for formaldehyde.

METHODOLOGY

An undergraduate comparative anatomy laboratory in Southeastern Ohio was the site of this study. Approximately 150 students were served by this facility on an annual basis. It consists of four permanently adjoined modular structures comprising 2820 square feet of laboratory space served by four nonrecirculating (i.e., 100 percent outside air) air handlers. The units maintained room temperature between 69–72°F and provided an estimated 2.5–3.2 room air changes per hour with the exterior doors closed.

Monitoring was carried out in a two-year period during the months of February and March. During study days the laboratory doors were closed more than 80 percent of the time owing to low outdoor temperatures. However, on several afternoons facility occupants propped open one or both outside doors to increase the amount of fresh air in the facility. It was observed that the doors were sometimes opened in the afternoon laboratory sessions, when accumulated formaldehyde levels were at their daily highest. The amount of fresh air introduced from the open doors could not be quantitated. There were no windows in the facility.

This laboratory used commercially preserved cats and sharks for dissection. Specimens were initially embalmed at a scientific supply house with a formaldehyde-containing solution, were rinsed of that solution, and shipped preserved in Ward-Safe. Ward-Safe Packing Fluid and Holding Solution (Ward's Natural Science Establishment, Rochester, NY) is a blend of 2.87 percent methanol, 1.44 percent 1,2-propanediol, 0.68 percent proprietary ingredients, and 95.01 percent water. Per the manufacturer's material safety data sheet, variable amounts of the original formalin fixative will leach into the specimen's shipping solution, and higher levels of the original fixative solution are noted to be possible in deep tissues of the shark or cat.[26] In this study the methanol vapors from the Ward-Safe were assessed in laboratory air as a surrogate for formaldehyde.

Video Exposure Assessment

Real-time formaldehyde concentrations were measured with a MIRAN 1B (Foxboro Company, Foxboro, MA), which had undergone a factory maintenance and calibration check immediately prior to use in this study. A photoionization detector (PID) with an 11.7 eV lamp and integral datalogger (RAE Systems, Sunnyvale, CA) was utilized to generate a digital signal for the purpose of overlay onto videotape. None of the available PID lamps (10.2, 10.6, or 11.7 eV) were responsive to formaldehyde, but the 11.7 eV lamp was responsive to methanol. As noted earlier, the major component in the Ward-Safe preservative is methanol (2.87% as prepared from concentrate). Therefore, the PID response to methanol (MW = 32) was considered a surrogate for formaldehyde (MW = 30) exposure, based on its correlation with the MIRAN 1B reading. The size and bulk of the MIRAN 1B precluded its use in a subject's breathing zone in order to directly generate the overlay signal.

A moderately strong correlation between the PID signal and the true formaldehyde concentration measured by the MIRAN 1B was determined by regression of simultaneously collected sampling data ($r = 0.49$). Using the correlation curve created in this manner (Figure 1), PID values (X) were equated to formaldehyde (Y) using Eq. 1. The PID response and sensitivity to methanol was judged to be adequate for the purpose of this study.

$$[Y = (0.6075\ X) + 0.1] \qquad [1]$$

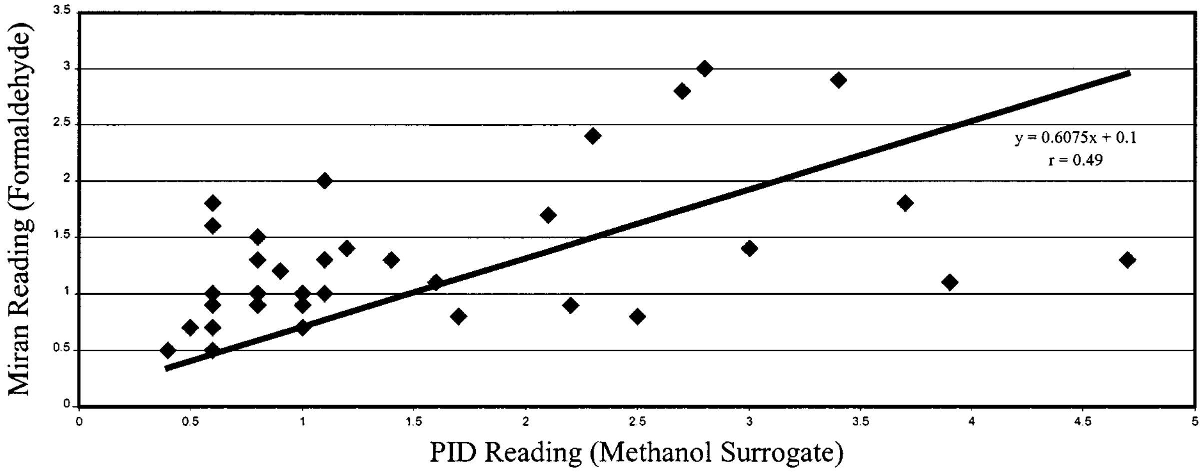

FIGURE 1
PID versus MIRAN correlation.

Total ionizables present were sampled while simultaneously videotaping laboratory actions performed. The PID inlet (Figure 2), was attached to the breathing zone of study subjects. Using synchronized time tracks from the datalogger and digital videotape, on-screen exposure concentration overlays were generated using Video Exposure Monitoring v.2.0 software created by NIOSH[27] and a video graphics computer board. During the study period, 18 video segments were created while observing a number of different operations, students, and specimen types.

Conventional Monitors

As a positive control of the surrogate monitoring method, personal and area samples were collected using conventional monitors. (Both active and passive samplers were utilized as part of a separate ongoing study, not described in this report.) A total of 32 personal samples (13 active, 19 passive) and 18 area samples (12 active, 6 passive) were obtained in morning and afternoon laboratory session sampling (n = 50). At a minimum, one of each sampler type was collected on each half-day sampling session during which video exposure assessments were generated.

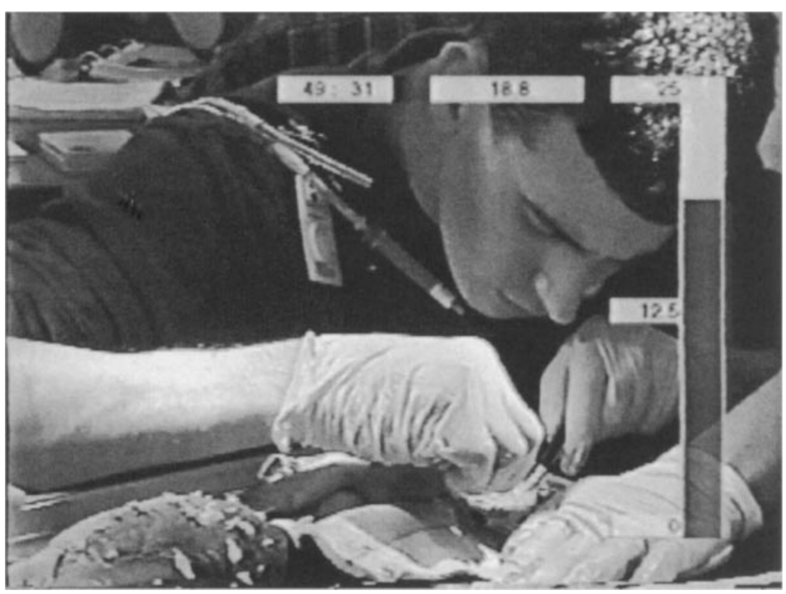

FIGURE 2
Typical monitor placement on student dissecting a shark. Open-ended tube on collar leads to the photoionization detector. PID value (18.8) corresponds to an 11.5-ppm formaldehyde concentration.

Area samples were collected by the specimen-containing vat, in the middle of a four-place dissection table, and in a corner of the room, distant to student dissections. Personal samplers were worn on the shirt collar or lapel and located within one foot of the subjects nose and mouth.

Personal and area concentrations were determined by use of passive dosimeters specific for formaldehyde (Assay Technology, Pleasanton, CA) as well as with active samplers employing DNPH-containing tubes. Both types of samplers were analyzed by AIHA-certified laboratories using NIOSH Method 2016. Dosimeters were typically exposed from 2–4 hours and a field blank was generated each sampling day. Active samplers were operated at calibrated flow rates of approximately 2 Lpm for between 2–4 hours. At this sampling rate, some tubes exceeded the maximum recommended loading recommended by the analysis laboratory.[28] A tube field blank for DNPH was generated each day of sampling (n = 4).

Finally, passive organic vapor monitors (OVM 3500, 3M, St. Paul, MN) were deployed to screen for possibly interfering volatiles within the laboratory. These dosimeters were placed alongside the formaldehyde dosimeters and exposed for identical periods. Figure 2 shows a student wearing the various personal monitors used in this study while performing close dissection.

Survey of Symptoms

To document the prevalence of irritation symptoms resulting from formaldehyde at the levels measured, room occupants were asked to complete an anonymous exposure questionnaire pertaining to the frequency of symptoms they experienced in laboratory sections. The survey was derived from literature-reported symptoms of exposure to formaldehyde.[19–21] Thirty-seven of 53 students (response rate = 70%), as well as two instructors, elected to participate. In the survey, subjects ranked a series of 14 symptoms of low-level formaldehyde exposure, as well as non-associated symptoms (hallucinations, chest tightness) included as a validity check. The fourteen symptoms listed were: watery eyes, burning eyes, burning nose, burning throat, nausea, cough or throat irritation, headache, hallucinations, eye irritation, sinus congestion, skin reactions, chest tightness, wheezing, and dizziness.

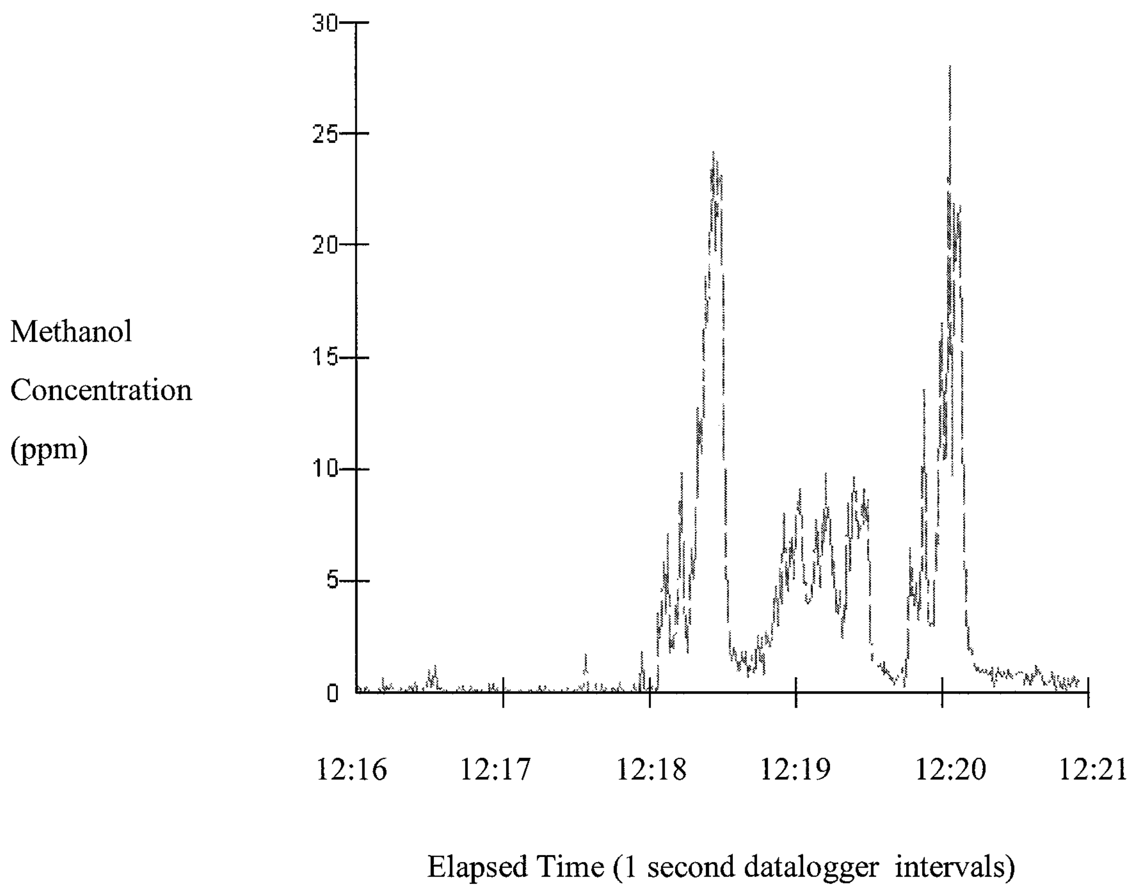

FIGURE 3
Typical PID response over a five-minute sampling interval demonstrating several transient peaks amid otherwise low background concentrations.

TABLE II
Conventional monitor results (formaldehyde concentrations (ppm) as determined by sampler type)

Sampler type	n	Minimum	Maximum	Average
Passive, personal	19	0.08	1.20	0.42
Active,[A] personal	13	0.07	0.43	0.21
Passive, area	6	0.15	0.22	0.21
Active,[A] area	12	0.06	0.38	0.16
Total samples = 50		Average, all monitors = 0.25		

[A]Values should be interpreted as minimums owing to overloading of analyte on some tubes.

RESULTS AND DISCUSSION

Conventional Monitors

Analytical results of the conventional monitors are presented in Table II. Average passive personal exposures were twice that of area samplers (0.42 ppm as compared with 0.21 ppm). The formaldehyde dosimeters gave time-weighted exposures of 0.08 to 1.2 ppm, with an overall combined personal and area average of 0.45 ppm. Active sampler results should be taken as representing formaldehyde concentration minimums, in that some tubes were overloaded with analyte. Thus, personal exposures indicated by the active samplers (0.07–0.43 ppm) were at least equal to or exceeded the range of values shown in Table II. Such is also the case for active area sampler results. All values found in this study are within the range of values of earlier studies. The monitors for volatile organic compounds showed only very low (i.e., ppb) exposures at or below the lower limit of detection for the chemicals screened (data not presented).

Video Exposure Assessments

All but one of the conventional monitoring devices indicated personal exposures that were in compliance with present standards. However, videotaped tasks demonstrated a notably

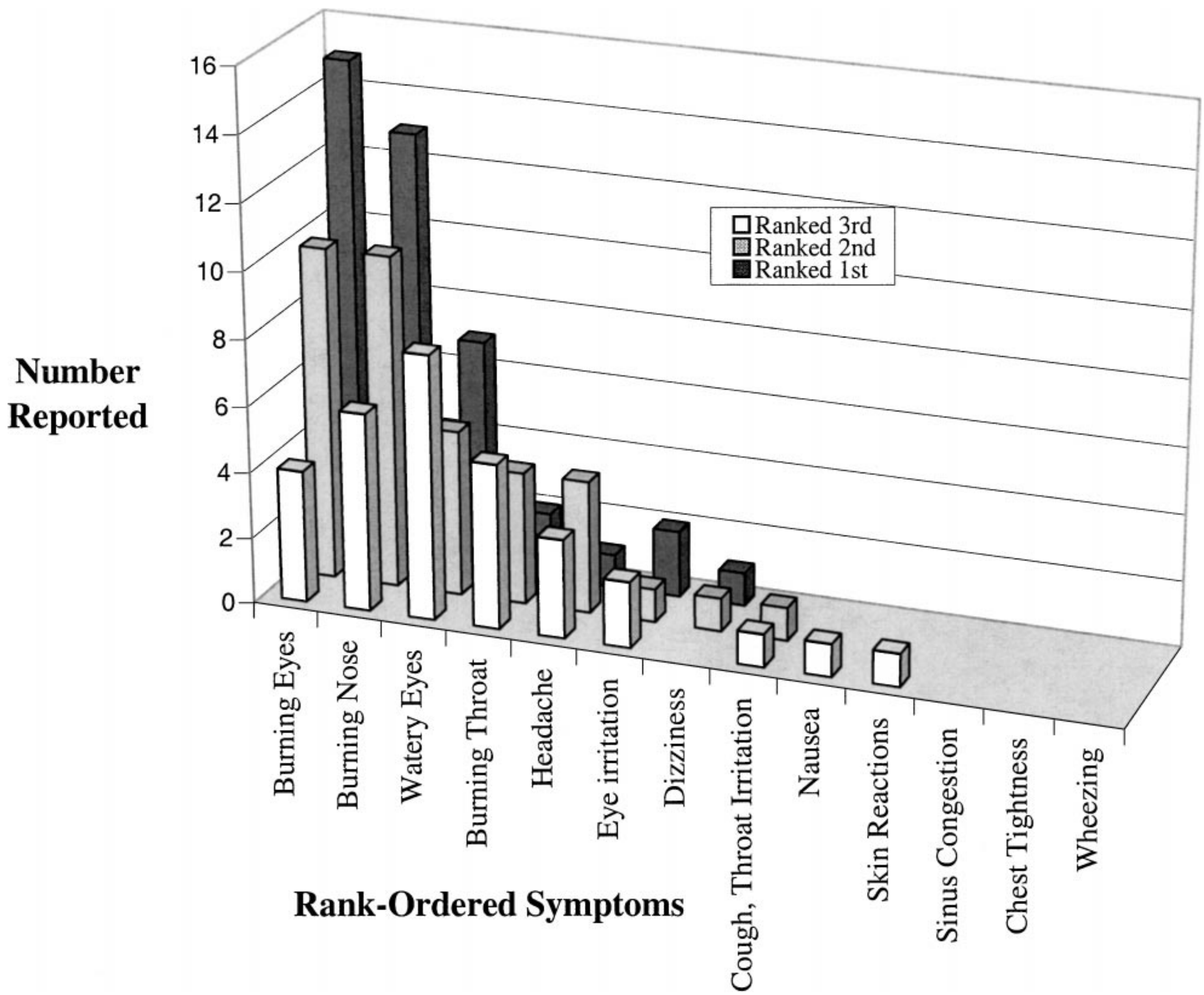

FIGURE 4
Self-reported laboratory-associated symptoms.

elevated exposure potential when overlaid with the PID response. PID values indicated numerous transient concentration peaks (Figure 3) in many of the operations studied. In particular, the frequent and extremely close proximity of the student's breathing zone to preserved specimens was revealed. Except for occasional postural adjustments students were often seen hunched over a specimen for 30 minutes or more at a time. The position of a student's nose to the sample had been observed while conducting monitoring, but it was not until the video taped task was scrutinized later that the extremely short distance between the formaldehyde source and the subject's breathing zone was truly appreciated. In numerous cases a student's nose and mouth were only 6–8 inches from the dissection in progress.

As demonstrated in Figure 2, PID values during close dissection indicated formaldehyde levels well in excess of the OSHA STEL of 2 ppm (i.e., 11.52 ppm). Native source video for Figure 2 is available in MPEG format for online viewing.[29] Furthermore, with the subject's actual breathing area so close to the source of contamination, the presumed validity of a collar- or lapel-mounted monitoring device as representative of a subject's breathing zone must be called into question. Application of Pythagorean geometry for a right angle triangle can be used to demonstrate that if the distance from the sampling device to the nose is 6 inches, and the nose is located at a right angle 6 inches from the specimen, then the sampling device is almost 1.5 times farther from the contaminant source than is the nose (i.e., square root of $72 = 8.5$ inches). Thus, although high PID values were observed, true exposures could well have been higher owing to the remoteness of the PID intake relative to the specimen.

In addition to the elevated concentrations recorded during specimen dissection, upon review of the digital overlays several other routine laboratory manipulations also demonstrated high values. Among these were the initial opening of the gut cavity, work on sharks (as opposed to cats), work in the peritoneum, and finding one's specimen in the specimen storage vat. As expected, those students seated at a dissection table who were only casual observers of a dissection did not demonstrate an elevated PID response. For such persons, conventional personal monitor results can be assumed to more closely reflect actual formaldehyde exposures.

Survey of Symptoms

Laboratory occupants' rankings of their three most frequently occurring laboratory-associated symptoms are shown in Figure 4. Burning eyes, burning nose, or watery eyes were most often reported as occurring during laboratory sessions: Almost 90 percent of the participants ranked one of those three symptoms as their most frequent complaint. Such symptoms are not associated with methanol exposure, but are consistent with formaldehyde exposure. Although the survey instrument has not been formally validated these results are compelling and congruent with other investigators' findings at similar concentrations.[2–4,9,11,12] Conversely, ailments not associated with formaldehyde (e.g., hallucinations, chest tightness) were never self-reported. Results therefore indicate an appreciable level of formaldehyde-induced irritation despite low, seemingly acceptable airborne concentrations as determined by conventional monitoring. As is often noted in indoor air quality complaints, over 80 percent of respondents indicated that their symptomology resolved after leaving the laboratory.

CONCLUSIONS

The facilities and procedures examined in this study were typical of many university anatomy and comparative anatomy laboratories. Furthermore, personal and area formaldehyde concentrations determined in this study were similar in concentration ranges to previous studies. For these reasons, the peak exposures recorded by the PID and visually associated with certain tasks in the video overlays can be taken as representative of actual exposures in many such laboratory settings. Universities with access to appropriate datalogging real-time instruments may wish to consider employing the video exposure assessment method in their laboratories. Requiring only a digital video camera, video overlay software available from NIOSH, and an inexpensive PC graphics overlay board, the method described here can be used to better characterize exposures where excessively high transient concentrations are suspected or possible.

Based on these findings, elimination of formaldehyde from human or animal anatomy laboratories should be the industrial hygienist's goal. It is possible that specimen suppliers might ultimately be held to a higher standard for supplying specimens free of residual formaldehyde. While it is beyond the scope of this article to discuss the toxicological significance of the high transient levels reported, effective engineering controls for their reduction are currently feasible. Specific tasks with notable exposures are fine dissection work, deep cavity examination, and retrieving preserved specimens from the storage vat. To better control dissection exposures, the use of local exhaust ventilation at each specimen station should be considered. Relocating specimen vats to areas with isolated ventilation or using hooded enclosures over such vats should be considered as methods to further reduce room and personnel exposures.

The utility of video exposure assessments for conducting enhanced, critical task evaluations of anatomy laboratory formaldehyde exposures has been shown to be highly relevant. Ninety percent of room occupants reported health symptoms consistent with the irritant effects of formaldehyde exposure. While more than 95 percent of the personal conventional samplers in this study showed typical, legally acceptable TWA exposures, videos with PID digital overlays demonstrated high transient personal formaldehyde exposures. Lacking this video exposure assessment data, formaldehyde levels in many previously evaluated laboratory environments may have erroneously been judged acceptable based solely on conventional time-weighted or STEL sampling.

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