

Assessment of workplace air concentrations of formaldehyde during and before working hours in medical facilities

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Abstract: Workplace air concentrations of formaldehyde (FA) in medical facilities where FA and FA-treated organs were stored and handled were measured before and during working hours and assessed by the official method specified by Work Environment Measurement Law. Sixty-percent of the total facilities examined were judged as inappropriately controlled work environment. The concentrations of FA before working hours by spot sampling were found to exceed 0.1 ppm in some facilities, and tended to increase with increasing volume of containers storing FA and FA-treated materials. Regression analysis revealed that logarithmic concentrations of FA during working hours by the Law-specified analytical method were highly correlated with those before working hours by spot sampling, suggesting the importance for appropriate storing methods of FA and FA-treated materials. The concentrations of FA during working hours are considered to be lowered by effective ventilation of FA-contaminated workplace air and appropriate storage of FA and FA-treated materials in plastic containers in the medical facilities. In particular, such improvement by a local exhaust ventilation system and tightly-sealed containment of FA-treated material were urgently needed for the dissecting room where FA-treated cadavers were prepared and handled for a gross anatomy course in a medical school.

Key words: Formaldehyde, Measurements A and B, Workplace air concentration, Area sampling, Spot sampling

Introduction

Formaldehyde (FA) has been extensively used not only as an intermediate in the synthesis of industrial chemicals but also as a preservative and disinfectant in medical facilities. The International Agency for Research on Can-

cer¹ revised carcinogenicity of FA from Group 2A (Probably carcinogenic to humans) to Group 1 (Carcinogenic to humans) in 2008. The Japan Society for Occupational Health recommended the occupational exposure limit of FA as 0.1 ppm in 2007², and the American Conference of Governmental Industrial Hygienists also proposed the same value as the notice of intended change in 2016³. The Japan Ministry of Health, Labour and Welfare designated FA as one of special control substances for potential occupational cancer and established an administrative control

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level (ACL) of 0.1 ppm⁴). It is required that the working environment in which FA is manufactured, prepared and handled be controlled with reference to the ACL and the standards for Working Environment Measurement and Evaluation^{5, 6}).

The present study was intended to assess FA-contaminated workplace air in medical facilities during working hours, using the Japan's official method with Measurements A and B⁶). Furthermore, the workplace air concentrations of FA during working hours were compared with those before working hours collected by spot sampling, in order to explore a possible source of indoor contamination with FA. We report that although local exhaust ventilation systems effectively reduced the workplace air concentrations of FA, storage of FA-treated material was an important determinant that influenced contamination of workplace air with FA.

Materials and Methods

Sampling of workplace air in medical facilities

A total of 25 medical facilities consisting of 14 pathology laboratories, 5 anatomy laboratories, 3 organ preservation facilities, 2 disinfection facilities, and one dissecting room for a gross anatomy course were chosen (Table 1). All the facilities were located in Fukuoka Prefecture. Two different kinds of workplace air sampling, i.e., area sampling during working hours by Measurements A and B and before working hours by spot sampling were conducted in the present study. The area sampling of FA-contaminated air in the medical facilities took place in each unit workarea during working hours according to the sampling method designated by the Working Environment Measurement Standards^{4, 5}). In Measurement A, six measuring points, each unit workarea covering 12 m² (28 m³) to 261 m² (626 m³), were selected for the area sampling in the medical facilities, while in Measurement B one measuring point was chosen, which is expected to exhibit the possibly highest concentration of FA. The sampling time was fixed at 10 min for both Measurements A and B. Spot sampling was performed before working hours at the center of the unit workarea and 50 to 150 cm high on the floor according to the sampling method used for investigation of sick building syndrome⁷). The spot-sampling time was fixed at 10 min except for a pathology laboratory (shown as No. 5 in Table 1) where the workplace air was collected for 24 hrs because no apparent source of FA emission was found, while the workplace was classified as Control Class II.

Collection and analysis of formaldehyde in workplace air

Measurement of FA mostly conformed to the NIOSH Manual of Analytical Method, No. 2016. Workplace air was collected in a cartridge⁸) containing silica gel coated with 2,4-dinitrophenylhydrazine (DNPH) (Sep-Pak XPO-Sure aldehyde sampler, Waters, Inc, USA) for 10 min at a rate of 1.0 l/min, using a suction pump (SKC Air Check 2000, USA). After elution of DNPH-FA complex with 10 ml of carbonyl-free acetonitrile, the eluate was subjected to high-performance liquid chromatographic (HPLC) analysis with a photodiode Array Detector (UV/UV-VIS) (Agilent 100, G1315A, USA) (NMAM, 2016)⁸). A working range of this method was 0.01 to 2.04 ppm for a 10-l air sample.

Assessment of workplace air quality during and before working hours

Geometric mean (GM) and geometric standard deviation (GSD) in each unit workarea are calculated from the observed FA concentrations. Using both GM and GSD, a 95% upper limit of the FA concentration equivalent to the first assessment value (E_{A1}) and an estimate equivalent to the arithmetic mean termed as the second assessment value (E_{A2}) can be derived from Eqs (1) and (2) according to the Working Environment Evaluation Standards⁵).

$$\log E_{A1} = \log GM + 1.645\sqrt{\log^2 GSD + 0.084} \quad (1)$$

$$\log E_{A2} = \log GM + 1.151(\log^2 GSD + 0.084) \quad (2)$$

The Working Environment Evaluation Standard recommends that a factor of 0.084 be added as a 90% upper limit (GSD=1.95) adjusting for between-day variation, when Measurement A is conducted in a single day⁹).

When E_{A1} is lower than the ACL, a probability that any workplace air concentration of FA in the unit workarea exceeds the ACL would be less than 5%, indicating that the unit workarea is appropriately controlled and thus classified into Control Class I. When E_{A2} is higher than the ACL, the unit workarea is evaluated as being inappropriately controlled and classified into Control Class III. When the ACL is between E_{A1} and E_{A2} , the unit workarea is classified into Control Class II. The unit workarea is also classified into Control Class I, II or III in comparison of the Measurement B-based FA concentration with either the ACL or its 1.5 times. Overall evaluation of the control class in each unit workplace is made according to the criteria given by the Working Environment Evaluation Standards⁵). The methods for sampling air and analysis of the

Table 1. Workplace air concentrations of FA in the facilities of hospitals and medical schools measured during and before working hours, and classification of the working environment into control classes according to the Working Environment Measurement and Evaluation Standards

No.	Facility	Hosp/Med school	Air volume of workplace (m ³)	Before working hours		During working hours							
				Spot sampling (ppm)	Apparent source of FA emission	Range in Volume of stored FA solution	Measurement A			Control Class by Measurements A and B	Overall Control Class	General ventilation or local exhaust ventilation installed	
							Range of FA concentrations by Measurement A (ppm)	GM (ppm)	GSD				Measurement B (ppm)
1		Hosp	87	0.09	Sealed glass vial	<1 /	0.10 ~ 0.24	0.16	1.36	0.15	3, 3	III	GV Run
2		Hosp	161	<0.01	Preserved organs to be prepared	<1 /	<0.01 ~ 0.01	0.01	1.00	0.01	1, 1	I	GV & LEV Run
3		Hosp	48	0.02	Sealed plastic storage container	1 ~ 99 /	0.01 ~ 0.03	0.02	1.64	0.02	1, 1	I	P-P Run
4		Hosp	72	0.12	Wet wooden dissecting table	<1 /	0.04 ~ 0.04	0.04	1.00	0.04	2, 1	II	P-P Stopped
5		Hosp	120	0.05**	None	<1 /	0.03 ~ 0.04	0.04	1.17	0.04	2, 1	II	LEV Run
6		Hosp	38	0.03	Sealed plastic storage container	1 ~ 99 /	0.03 ~ 0.03	0.03	1.00	0.04	1, 1	I	GV & LEV Run
7	Pathology Lab	Med sch	144	0.02	None	<1 /	0.02 ~ 0.03	0.02	1.43	0.03	1, 1	I	None
8		Med sch	89	0.02	None	<1 /	0.02 ~ 0.04	0.02	1.49	0.02	1, 1	I	GV Run
9		Med sch	28	0.04	Sealed glass	1 ~ 99 /	0.01 ~ 0.06	0.02	2.27	0.05	2, 1	II	GV Run
10		Hosp	48	0.02	Sealed bucket	100 ~ 999 /	0.02 ~ 0.02	0.02	1.00	0.03	1, 1	I	GV & LEV Run
11		Hosp	72	0.12	None***	1 ~ 99 /	<0.01 ~ 0.01	0.01	1.00	0.02	1, 1	I	LEV Run
12		Hosp	89	0.05	Sealed plastic storage container	1 ~ 99 /	0.02 ~ 0.06	0.03	1.54	0.04	2, 1	II	GV & LEV Run
13		Hosp	65	0.04	Wet wooden dissecting table	<1 /	0.05 ~ 0.10	0.07	1.30	0.07	2, 1	II	GV Run
14		Med sch	96	0.01	None	1 ~ 99 /	0.02 ~ 0.04	0.02	1.33	0.03	1, 1	I	LEV Run
15		Hosp	71	0.36	Sealed bucket	1,000 / <	0.43 ~ 1.02	0.68	1.49	0.79	3, 3	III	GV Run
16		Hosp	84	0.02	Preserved organs to be prepared	1 ~ 99 /	0.02 ~ 0.03	0.02	1.23	0.04	1, 1	I	GV Run
17	Anatomy Lab	Hosp	134	0.04	Preserved organs to be prepared	1 ~ 99 /	0.02 ~ 0.03	0.03	1.18	0.04	1, 1	I	None
18		Hosp	55	0.04	Sealed plastic storage container	1 ~ 99 /	0.04 ~ 0.06	0.05	1.59	0.07	2, 1	II	GV Run
19		Hosp	55	0.25	Sealed bucket	1 ~ 99 /	0.24 ~ 0.31	0.28	1.11	0.47	3, 3	III	GV Run
20		Med sch	129	0.03	Sealed glass vial	1 ~ 99 /	0.03 ~ 0.06	0.04	1.36	0.03	2, 1	II	GV Run
21	Organ preservation	Med sch	50	0.04	Sealed bucket	100 ~ 999 /	0.11 ~ 0.37	0.22	1.62	0.58	3, 3	III	None
22		Med sch	130	0.18	Sealed plastic storage container	100 ~ 999 /	0.04 ~ 0.10	0.07	1.39	0.06	2, 1	II	GV & LEV Run
23	Disinfection	Hosp	103	<0.01	None	1 ~ 99 /	<0.01 ~ 0.12	0.02	3.25	0.13	2, 2	II	GV & LEV Run
24		Hosp	96	0.01	None	1 ~ 99 /	0.01 ~ 0.03	0.02	1.43	0.14	1, 2	II	LEV Run
25	Dissecting room for the gross anat-omy course*	Med sch	626	0.06	FA-treated cadavers in sealed plastic bags	100 ~ 999 /	1.16 ~ 2.12	1.56	1.26	2.04	3, 3	III	GV Run

Control classes I, II and III were described in Materials and Methods.

Control Classes of the workplaces were evaluated in the terms of overall evaluation and evaluations by Measurements A and B as described in the rightside columns.

GV: General ventilation, LEV: Local exhaust ventilation, P-P: Push-Pull type LEV

*: This facility was excluded from the present analysis.

** : The spot sampling time was 24 hrs instead of 10 min.

***: See the text for the contaminant source.

FA concentrations before working hours are the same as those for Measurements A and B.

The FA concentrations obtained by spot sampling and Measurements A and B were examined for normality of distribution by the Shapiro-Wilk test. It was found that all these data sets followed logarithmic normal distribution. Thus, we examined the relationship between the logarithmic concentrations of FA by Measurement A or B and those by spot sampling by conducting a linear regression using the least square method. Statistical significances of the correlation coefficients and slopes were tested using Pearson's product-moment coefficient. All of the statistical analyses were performed using SAS15.03 software (SAS Institute, Cary, NC, USA).

Results

In the laboratories of pathology and anatomy, workers were exposed to FA, when the dissected organs were put into containers or glass bottles preserving FA and FA-treated materials, and when the FA-treated organs were prepared for microscopic examinations. FA was also used for disinfecting surgical tools in two hospitals. The present study revealed that number of the facilities classified as Control Classes I, II and III were 10 (40%), 10 (40%) and 5(20%), respectively (Table 1), indicating that only 40% of the total facilities examined were appropriately controlled. Local exhaust ventilation systems were set up in 60% of the facilities classified as Control Class I. On the other hand, no local exhaust ventilation system was installed in the workplaces classified as Control Class III. In the facility (shown as No. 25 in Table 1) where teaching staff prepared a gross anatomy course with cadavers, they opened 25 sealed bags containing FA-treated cadavers, placed those on the dissecting tables, and then started to teach dissecting operations to be performed by the medical students. Two sealed boxes containing FA-treated brain, and the dissected brains were washed in a sink by water before presentation to the anatomy course. Exceptionally high concentrations of 1.56 ppm FA (geometric mean) by Measurement A and 2.04 ppm by Measurement B were observed during the gross anatomy course.

The concentrations of FA in workplace air collected before working hours by spot sampling were 0.07 ± 0.08 ppm (means \pm SD), ranging from less than 0.01 ppm in the pathology laboratory (No. 2) to 0.36 ppm in the anatomy laboratory (No. 15). It was found that in all the facilities except in the dissecting room for the gross anatomy course (No. 25), relatively small volume of FA and FA-treated

materials was stored in sealed containers such as glass vials, plastic containers and buckets. Volume of stored FA solution was found to range from less than 1 to 999 l. The FA concentrations in the workplace air collected before working hours by spot sampling tended to increase with increasing volume of the containers storing FA and FA-treated materials. Mean FA concentration before working hours was 0.05 ppm for the workplaces where less than 1 l to 99 l of the containers storing FA and FA-treated materials were stored, and 0.13 ppm for those where larger than 100 l of the containers storing FA and FA-treated material were stored. Table 1 shows that the concentrations of FA after working hours by spot sampling were much higher in the facilities numbered 4, 11 and 22 than those during working hours by Measurement A. The reason why the increased concentration of FA was observed at the facility (No. 4) after working hours was that the wooden dissecting table contaminated with FA was dried after working hours, while the door was kept closed. The other facility (No. 11) was characterized by storage of FA-treated organs in loosely capped glass bottles placed on the shelf. The FA concentration before working hours by spot sampling was 0.18 ppm in the organ preservation facility (No. 22) where many loosely sealed plastic storage containers having FA and FA-treated organs were placed. On the other hand, the medical facility (No. 21) where 40 sealed buckets containing FA and FA-treated organs were preserved was well-maintained at a low level of 0.04 ppm FA, but work environment of that facility (No. 21) was judged as Control Class III being inappropriately controlled during working hours. Such lowered concentration of FA before working hours was due presumably to the use of tightly sealed containers. As an episodic example of a hospital pathology laboratory (No. 11) where 0.12 ppm FA was found by spot sampling, we were not able to find any contaminant source at the time of spot sampling. The later re-examination revealed that a plastic container storing FA and FA-treated organs was kept in an apparently enclosed shelf from which FA was emitted to the environment. FA concentrations in the shelf were extremely high ranging from 2.86 to 4.90 ppm.

There was no significant correlation between air volumes of the medical workplaces where the FA and FA-treated materials were stored and FA concentrations by spot sampling or Measurement A or B.

Figure 1 shows linear regression lines of logarithmic concentrations of FA during working hours by Measurements A (dotted lines) and B (solid lines) against those before working hours by spot sampling. Two thin curves

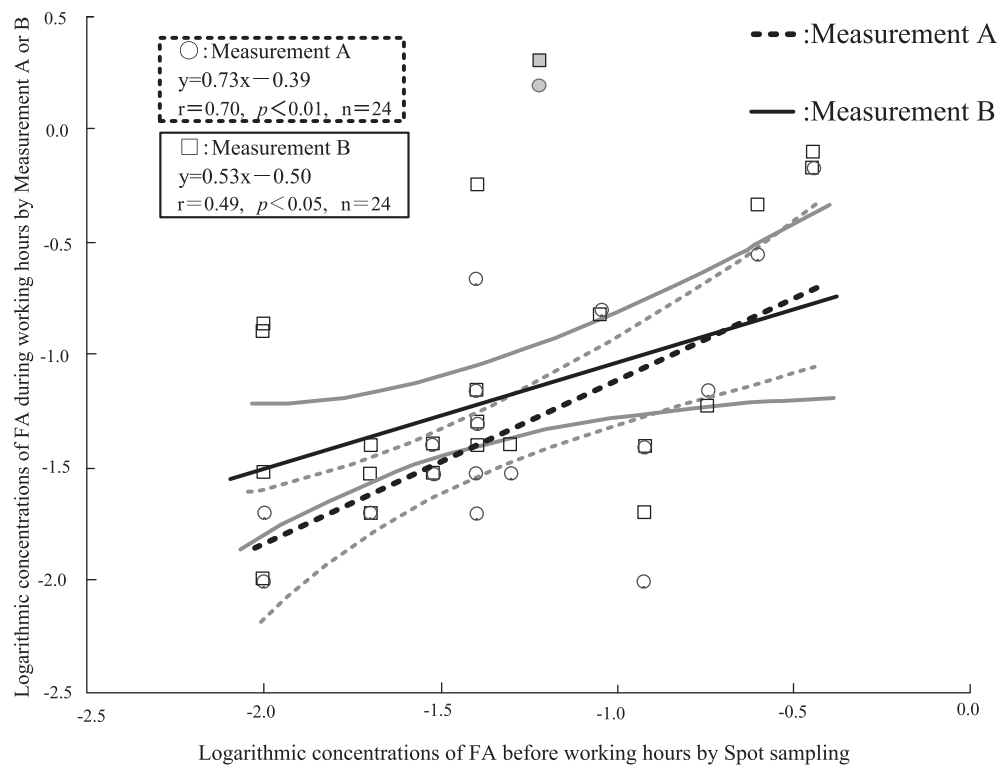


Fig. 1. Relationship between FA concentrations before working hours and those during working hours

of each regression line indicate the upper- and lower-most 95% confidence limits. Open circles and squares represent concentrations of FA by Measurements A and B, respectively, in the 24 medical facilities, while filled circle and square indicate the FA concentrations by Measurements A and B in the dissecting room (No. 25). These two filled symbols were found to fall far beyond the uppermost 95% confidence limit curves. The regression equations were obtained from the 24 data excluding those for the dissecting room. The regression line obtained by a total of 25 medical facilities was $y=0.79X-0.25$ ($r=0.62$, $p<0.01$) for Measurement A and $y=0.59X-0.35$ ($r=0.45$, $p<0.05$) for Measurement B. On the other hand, the regression line obtained by the 24 data except for those in the dissecting room (No.25) was found to be $y=0.73X-0.39$ ($r=0.70$, $p<0.01$) for Measurement A and $y=0.53X-0.50$ ($r=0.49$, $p<0.05$) for Measurement B. However, either for a total of 25 data or the 24 data except for the dissecting room, there was no statistically significant difference in the correlation coefficient between the regression line obtained by Measurement A and that obtained by Measurement B.

The data from the dissecting room for the gross anatomy course was excluded from the present regression analysis for following two reasons: First, this room was used only for the gross anatomy course twice a year, and was consid-

ered not to be categorized as a workplace but as a lecture room. Second, any medical staff did not use this room for their daily work.

Discussion

It was found in the present study that number of the medical facilities classified as Control Classes I, II and III were 10 (40%), 10 (40%) and 5(20%), respectively. The workplace classified as Control Class I was judged as the appropriately controlled work environment. The workplace classified as Control Class II was required to take actions for improvement of the work environment. Twenty-percent of the total workplaces were found to be classified as Control Class III in which an immediate action is required for abatement of workplace air concentrations of FA by industrial hygiene engineering measures.

We recommended installing the local exhaust ventilation systems in such inappropriately controlled workplaces. It was also found that the workplace air concentrations of FA during working hours tended to increase with an increase in the FA concentrations before working hours by spot sampling. This finding suggested that proper containment of FA and FA-treated materials or their replacement outside the workplaces would be effective for abatement of

FA concentrations in the workplace air.

The indoor FA concentrations before working hours in the medical workplaces, all of which were located in Fukuoka Prefecture, were much higher than atmospheric concentrations of FA in Fukuoka City: The atmospheric concentration of FA in Fukuoka City was reported to range from $0.78 \mu\text{g}/\text{m}^3$ (0.64 ppb) to $6.7 \mu\text{g}/\text{m}^3$ (5.5 ppb) with the mean value of $2.8 \mu\text{g}/\text{m}^3$ (2.3 ppb) averaged over 6 sampling spots in 2008¹⁵⁾.

The FA concentrations during working hours obtained by Measurement A appeared to be highly correlated with those before working hours by spot sampling in comparison with those by Measurement B.

It was noteworthy in the present study that the dissecting room for the gross anatomy course was highly contaminated with FA of greater than 1 ppm during the anatomy course. This finding agreed well with the results^{10–14)} by some investigators including Kikuta *et al.*¹²⁾ who reported that air concentrations of FA in a gross anatomy laboratory were reduced from greater than 1 ppm as determined by Measurement A to the low levels below 0.1 ppm by installing the effective local exhaust ventilation system. Therefore, we recommended use of doubly sealed containment for preserving the FA-treated cadaver, that is, the cadaver was placed at first in a sealed bag, and then put into a sealed container, in addition to setting up a local exhaust ventilation system in the dissecting room.

It was also noteworthy that the FA concentrations before working hours tended to increase with increasing volume of the container storing FA and FA-treated materials. The present finding suggests that contamination of the medical workplaces with FA during working hours is attributed not only to handling of FA and FA-treated materials during working hours but also an inappropriate method for storage of FA and FA-treated materials inside the facilities.

Conclusion

It was found in the present study that workplace air concentrations of FA during working hours by Measurement A were highly correlated with those before working hours by spot sampling. This finding can be taken to indicate that the workplace was contaminated with FA not only through inappropriate handling of FA and FA-treated materials during working hours but also through inappropriate storage of FA and FA-treated materials inside the workplaces. Use of a tightly sealed container storing FA and FA-treated materials or doubly sealed containment of those materials is an important determinant for well-controlled work envi-

ronment, in order to effectively reduce room-air concentrations of FA before working hours to an indoor guideline for FA below 0.08 ppm ($0.1 \text{ mg}/\text{m}^3$) set by the Japan Ministry of Health, Labour and Welfare¹⁶⁾. It was found in the present study that any local exhaust ventilation system was not installed in the workplaces which were judged as Control Class III. Therefore, setting up the effective local exhaust ventilation system is of prime importance for improving such inappropriate facilities.

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