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PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Pakistan Journal of Biological Sciences 10 (14): 2341-2347, 2007
ISSN 1028-8880

Determinants of Exposure to Chemical Pollutants in Wet X-Ray Film Processing in Iran

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Abstract: The aim of the current study was to measure glutaraldehyde, acetic acid and sulfur dioxide and levels inside wet x-ray processing areas in a developing country and comparing data with those in developed countries. Forty-five radiographers from 10 educational hospitals affiliated to the Tehran University of Medical Sciences (TUMS) in Tehran, Iran participated in this descriptive-analytical study. Exposure to glutaraldehyde (a constituent of developer chemistry), acetic acid (a constituent of fixer chemistry) and sulfur dioxide (a byproduct of sulfites present in both developer and fixer solutions) was measured in all participants as well as area exposure. Average full-shift exposure to glutaraldehyde, acetic acid and sulfur dioxide were 0.0018, 2.65 and 1.64 mg m^{-3}, respectively. The results showed that the TUMS radiographers full-shift exposures are generally lower than the American Conference of Governmental Industrial Hygienists (ACGIH) recommended levels. The concentration of glutaraldehyde collected by area sampling (darkroom) was almost five times (0.0104 mg m^{-3}) greater than taken by personal sampling. Exposure to the chemical pollutants in the currents study were generally higher than in developed countries. Identification of these key exposure determinants is useful in targeting exposure evaluation and controls to reduce developer and fixer chemicals exposures in the radiology departments. Employing of a digital imaging system that do not involve wet x-ray processing of photographic film would be a useful device for radiographers protection.

Key words: Acetic acid, glutaraldehyde, wet x-ray processing, occupational exposure, radiographers, sulfur dioxide

INTRODUCTION

Full-service hospitals generally have a wet x-ray processing where technicians expose to the liquid chemicals necessary for developing and fixing the film. The photographic developing solutions used in wet x-ray departments consist of two parts, a fixer and a developer. The fixer normally contains 5-10% hydroquinone, 1-5% potassium hydroxide and less than 1% glutaraldehyde. Acetic acid is also used as a component for stop baths and fixer solutions. Wet x-ray film processing consist of two main stages; stabilizing of image during the developing process using reducing agents such as glutaraldehyde and fixed the image by agents that dissolve and remove the unused silver halides. These chemicals eventually reach the end of their usefulness and must be disposed of as hazardous vapor fume and wastes. The radiographers have potential exposure to wet x-ray processing chemicals that include sensitizers and irritants such as glutaraldehyde (GA), sulphur dioxide (SO_2), formaldehyde and acetic acid (Burge, 1989; Scobbie *et al*., 1996; Tescchke *et al*., 2002). Aldehydes, especially GA with highest vapor pressure have been identified as a major cause of occupational asthma in wet x-ray processing (Scobbie *et al*., 1996; Cullinan *et al*., 1992; Gannon *et al*., 1995). Numerous studies have described cases of respiratory effects such as asthma in radiographers (Gordon, 1987; Schneider, 1994; Gordon, 1989). Therefore, implementation of effective control strategies is very important in reducing the incidence and prevalence of GA asthma. During the wet x-ray processing, radiographers also have shown a variety of symptoms such as headache, sore throat, fatigue, sinus problems, oral ulcers, skin rash, chest pains, heart arrhythmias and eye irritation (Hewitt, 1993; Goncalo *et al*., 1984; Liss *et al*., 2003). There are few previous studies on chemical pollutant such as glutaraldehyde, sulphur dioxide and acetic acid concentration at the wet x-ray processing. Teschke *et al*. (2002) has determined exposure levels to GA, acetic acid and SO_2 at concentration of 0.0009, 0.09 and 0.08 mg m^{-3}, respectively, during hospital and clinic x-ray film processing in the province of British Columbia. Almost 100% of 97 samples measurements were lower the current occupational exposure limits. Gannon *et al*. (1995) measured median personal short term GA

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concentrations of 0.016 mg m^{-3} and long term concentrations of 0.041 mg m^{-3} in endoscopy units, but in x-ray darkrooms, the results of all 19 samples were less than 0.009 mg m^{-3}. The objective of this research is to evaluate the determinants of GA, acetic acid and SO_2 exposures for the radiographers in 10 educational hospitals of TUMS in Iran. Identification of the important factors influencing exposure levels for darkrooms, general environment, machine characteristics and facility will enable the development to estimate the exposures of sampled workers, as well as to provide to prioritize future exposure evaluations and intervention efforts.

MATERIALS AND METHODS

This study was conducted in 10 educational hospitals of the Tehran University of Medical Sciences (TUMS) located in Tehran, the capital of Iran. In the medical radiology departments, darkrooms and processing area are typically very small little attention to design. The special design and construction of darkroom with low-level side windows and roof opening (vents) facilitated the natural ventilation. The facility's film processing rooms were constructed and installed without recommended exhaust hoods or segmented side doors. In this hospitals, all of wet x-ray film processing rooms do not have a general ventilation systems. Consequently, in addition to vapor and fumes contamination arising from wet x-ray film processing. With regards to vapor pressures of GA and acetic acid and other its properties such as standard air sampling and analysis methods, these two reagents were selected for air sampling. In the wet x-ray processing, where the fixer solution is heated, we have gaseous contamination such as SO_2 that in this research this gas pollutant was selected for air sampling. Air sampling took place over a 4-month period during winter and spring 2005. This study has been carried out in 3 stages as follows:

Exposure to GA: Radiographers, exposure to GA was measured using the Occupational Safety and Health Administration (OSHA) method 64 (OSHA, 1998). Both personal (n = 45) and area (n = 54) samples were taken. Area samples were collected in the fixed location at operators, work stations in the darkrooms. In order to determine the GA, samples were collected using glass fiber filter with 37 mm diameter, treated with 2-4 Dinitro phenylhyrazine (DNPH) and an open-faced holder connected to a personal sampling pump (SKC, model 224-PXR3) operating at a flow rate of 1 L min^{-1}. However, due to the fact that the radiographers, exposure to developer solutions was mostly intermittent, the personal air sampling pump was only switched on when the radiographers were actually working in the darkrooms.

Exposure to SO_2: Determination of SO_2 concentration was done by National Institute of Occupational Safety and Health (NIOSH) 1977 method 6004. Equipment for SO_2 gas sampling consisted of a personal sampling pump (SKC, model 222-3) and a midget impinger. The absorbing solution was H_2O_2, 0.3 N. Sampling was done at a flow rate of 1 L min^{-1}.

Exposure to acetic acid: Following the fixer solutions concentrations air sampling, radiographers, exposure to acetic acid was measured using the detector tube. The detector tube method is a colorimetric analysis technique, in which a gas or vapor sample is drawn by means of a pump through a solid reagent layer. The pumps were calibrated before and after sampling using a soap-film flow meter and mean flow rates were used to calculate air volumes samples.

Data analysis: SPSS for windows version 11.5 was used for statistical processing. Data obtained this study were analyzed using statistical tests including one-way analysis of variance (ANOVA) and t-test.

RESULTS

Personal exposure: This research was carried out in 10 educational hospitals in Tehran, Iran. The radiographers were 35(47.9%) female and 38(52.1%) male and their average ages were 32.11 ± 7.42 and 43.9 ± 8.09 years in the mentioned areas, respectively. The average of their work history was 75.29 ± 48.23 and 162.2 ± 94.72 months, respectively. Approximately 222 samples for the airborne chemical pollutants were collected from 10 hospitals during winter and spring 2005. The arithmetic and geometric means of GA and SO_2 exposures to breathing zones of radiographers are shown in Table 1 and 2. Efforts were directed toward conducting air sampling during work tasks representative of work performed during the entire shift. With regard to the findings the radiographers who worked in the hospital of number 6 had the highest exposure to GA: 0.0029 mg m^{-3}, while the hospital of number 4 radiographers had the lowest exposure to GA: 0.0011 mg m^{-3}. One-way variance analysis which done between different exposures in the hospitals showed that there were no significant differences between the personal exposures to GA and other chemical pollutants in the hospitals ($p>0.05$). The American Conference of Governmental Industrial Hygienists (ACGIH) ceiling (10 min) Threshold Limit Value (TLV) for GA is equivalent

Table 1: Concentration of GA (mg m^{-3}) in the breathing zones of radiographers during a full work shift in the hospitals

Hospitals	No. of samples	Arithmetic mean	Standard deviation	Geometrics mean	Geometrics standard deviation
1	10	0.0017	0.0006	0.0016	1.14
2	6	0.0015	0.0006	0.0013	1.21
3	5	0.0014	0.0004	0.0013	1.06
4	5	0.0011	0.0003	0.0010	2.44
5	7	0.0016	0.0005	0.0015	1.69
6	9	0.0029	0.0040	0.0020	1.74
Total	42	0.0018	0.0019	0.0015	1.25

Table 2: Concentration of SO_2 (ppm) in the breathing zones of radiographers during a full work shift in the hospitals

Hospitals	No. of samples	Arithmetic mean	Standard deviation	Geometric mean	Geometrics standard deviation
1	8	0.65	0.23	0.60	1.67
2	5	0.52	0.08	0.51	1.22
3	5	0.76	0.04	0.75	1.02
4	5	0.55	0.13	0.54	1.04
5	8	0.64	0.23	0.61	1.02
6	8	0.70	0.10	0.69	1.02
7	5	0.57	0.03	0.56	1.01
Total	44	0.63	0.16	0.61	1.15

Table 3: Concentration of acetic acid (ppm) in the darkroom area of the hospitals

Hospitals	No. of samples	Arithmetic mean	Standard deviation	Geometric mean	Geometrics standard deviation
1	7	1.22	0.20	1.21	1.18
2	6	0.83	0.22	0.81	1.06
3	7	1.20	0.20	1.20	1.03
Total	20	1.11	0.27	1.07	1.09

Table 4: Concentration of GA in the darkroom areas of 10 hospitals (mg m^{-3})

Hospital	No. of samples	Arithmetic mean (SD)	Geometric mean (GSD)
1	7	0.0086 (0.005)	0.012 (2.69)
2	5	0.0025 (0.0012)	0.0086 (1.017)
3	5	0.0081 (0.0049)	0.0058 (3.9)
4	5	0.0071 (0.0023)	0.0078 (1.07)
5	5	0.0123 (0.0023)	0.007 (1.028)
6	5	0.0123 (0.0035)	0.0119 (1.069)
7	8	0.0123 (0.0047)	0.116 (1.099)
8	5	0.0063 (0.0009)	0.006 (1.02)
9	4	0.007 (0.002)	0.0067 (1.024)
10	5	0.0082 (0.0027)	0.0079 (1.09)

Table 5: Correlation between darkroom volume and area GA and acetic acid concentration

Variable	No. of samples	Mean	SD	Range	p-value	Model r^2
Darkroom volume (m_3)	10	30.41	13	19-52	-	-
GA (mg m^{-3})	50	0.0094	0.0044	0.00057-0.021	p = 0.035	-0.65
SO_2 (ppm)	44	0.63	1.64	0.28-1.14	p = 0.7	-0.44

SD = Standard Deviation, r^2 = The proportion of variance explained

to 0.22 mg m^{-3} (0.05 ppm). The ACGIH, TLV for acetic acid and SO_2 are also equivalent to 25 mg m^{-3} (10 PPM) and 5 mg m^{-3} (2 ppm), respectively (ACGIH, 2002). The mean exposure level of GA was below the TLV, recommended by ACGIH, as were levels for both acetic acid and SO_2. The one-way analysis of variance also which were performed for the comparison of mean concentration of GA and acetic acid in the hospitals, darkrooms showed that the corresponding mean level were significantly different ($p<0.05$), but the mean exposure level of all were below TLV level. In the facilities studied, there were 15 wet x-ray processing machines, that most housed in separate rooms. None of these rooms had general ventilation and the x-ray processors did not have local exhaust ventilation.

Area exposure: During the study, 45 samples for airborne GA and 20 samples for acetic acid were collected from darkrooms of the hospitals. The arithmetic and geometric means of GA and acetic acid to work rooms area are shown in Table 3 and 4. As the Table shows, the mean area exposure to GA and acetic acid were below the ACGIH (1997) TLV. Table 5 provides the correlation between darkroom volume and area GA and personal SO_2 concentration. Results showed that, dark room volume only with GA concentration had negatively correlated ($r = -0.65$, $p = 0.035$). With regard to the finding, higher dark room dimensions appear to be associated with lower exposures of GA. Personal exposure to GA in all dark rooms was also measured. The correlations between this concentration and the volume of the dark rooms were to

Table 6: Characteristics of film processing machines and 10 hospital facilities where exposures were measured

Characteristics	Hospital facilities (N = 10)
No. of processing machines	15
No. with no local exhaust ventilation (%)	10 (100%)
No. with no general room ventilation (%)	10 (100%)
Location of film processing machines	
Darkroom (%)	10 (100%)
Day light (%)	6%
Mean No. of films processed/machine/week (SD)	924.4±1014.4
Machine has silver recovery unit (%)	0
Machine has open drainage (%)	0
Mean No. of radiographers on site (SD)	6.3±3.1
Mean No. of machines on site (SD)	1.1±0.31
Mean No. of rooms in which processing	
Machines located (SD)	2.1±0.6
Mean No. of film processed, week (SD)	13.0±100

Note: SD = Standard Deviation

Table 7: Characteristics of 45 radiographers whose exposures were measured and their work on the sampling day

Characteristics	Hospital facilities (N = 10)
Radiography exposure	
Mean years on site (SD)	10.10±6.28
Number female (%)	47.9
Mean shift length (hours) (SD)	37.2±9.3
Number of films processed in dominant machine used by subject on sampling day (SD)	26.2±20.3
Load and remove a processed film from an automatic processing machine	
Less than 1 per week (%)	1
At least 1 per week but less than daily (%)	4
Daily (%)	95
Frequency of processor replenishment by pouring chemicals	
Never (%)	45.6
At least 1 week but less than daily (%)	14.7
Daily	19.1
Reported PPE availability	
Gloves available on site (%)	85
Goggles available on site (%)	30
Dust mask available on site (%)	40
Cartridge respirator available on site (%)	0
Reported use to PPE on sampling day	
Wore gloves (%)	20
Wore other protective equipment (%)	20
Reported smelling processing chemicals on sampling day (%)	90

Note: SD = Standard Deviation; PPE = Personal Protective Equipment

be -0.45 and 0.08, respectively, but none were significant ($p>0.05$). Personal exposure to GA was not shown to be associated with dark rooms volume, although the GA measure itself has an association.

Other characteristics of the processing: Table 6 provides conditions of the 15 x-ray processing machines. In the traditional wet film-based imaging have always relied on film processing that uses liquid developer and fixes chemicals. In the most wet x-ray processing, all machines used automated mixing. There were no local exhaust ventilation on the sampling days. The characteristics of the radiographers included in this exposure monitoring survey and the tasks performed on the sampling days are shown in Table 7. On the sampling days the dominant machines processed an average of 300 films, on target for the weekly workload of about 924 (SD = 0.144) films per machine reported for these facilities. Relatively, little time (15 min) was spent in the darkroom or loading film. Although gloves and goggles were available at most facilities, only nine individuals reported using gloves on the sampling days. Personal protective equipment use was reported at 20%. Odor from processing chemicals on sampling days was reported in 90-100 of days.

DISCUSSION

This study was carried out in 10 educational hospitals in the capital of Iran, to assess radiographers' occupational exposure to GA, acetic acid and SO_2. In these hospitals, the wet x-ray process flow and the machinery used to process the radiographs are generally imported from developed countries without the application of adequate engineering controls and proper safe work practices. In developing countries, the combination of these conditions and relaxed occupational health and safety regulations can result in greater exposure to air pollutants in the workplace as well as higher disease incidence than found in developed countries.

Glutaraldehyde (GA), acetic acid and sulfur dioxide (SO_2) concentrations during wet x-ray film processing in radiology departments have been reported in several studies in the past 10 years. A direct comparison of the results of the chemical pollutants in the wet x-ray film processing study results with these previous studies is difficult for a number of reasons. Often the sampling times, the measuring using method and technique of analysis are quite different, the results were described with a variety of descriptive statistics (arithmetic mean, geometric mean, etc.), the objective of the studies varied greatly (sampler comparison, method evaluations, surveillance and epidemiology) and the studies were conducted in different countries and covered different time span and work task and workers condition. All inhalation exposures to GA, acetic acid and SO_2 in this study were below the existing occupational exposure standards of the ACGIH. Low exposures to GA, acetic acid and SO_2 have been observed by other researchers (Teschke *et al*., 2002; Gannon *et al*., 1995; Lienster *et al*., 1992). A study of British Columbia, Canada reported a arithmetic means concentrations for GA, acetic acid and SO_2, of 0.0009, 0.09 and 0.08 mg m^{-3}, respectively. Gannon *et al*. (1995), also measured personal short and long term GA concentration of 0.009 mg m^{-3}. A another survey of united kingdom darkrooms of radiology department measured a arithmetic mean GA concentration from 0.003 to 0.006 mg m^{-3} (Lienster *et al*., 1992). Glutaraldehyde and other chemical pollutants such as acetic acid and SO_2 exposures in each of these studies were all quite low, as was reported in this study. This is the first study to report GA, acetic acid and SO_2 exposures levels in radiology departments of the developing country. Little work has been done to date to evaluate the determinations of chemicals including sensitizers and irritants such as GA, acetic acid and SO_2 exposure levels in the radiology departments in developing countries. With regards to the ceiling TLV (0.20 mg m^{-3}) of GA, personal exposures were measured thought a full shift, so the maximum full-shift GA exposure measured was low less than 6/100 of the ceiling limit; it is extremely unlikely that the ceiling limit was exceeded for short periods within a shift. In general, the concentrations found by personal sampling in this study seem to be higher than those reported else where. Despite, low levels exposure of GA, acetic acid and SO_2 in the radiology departments, we must considered in the literature includes of reported health effects. With regards to exposure measurements below detection limits, Gannon *et al*. (1995) reported two cases of work-related asthma in radiographers. Each case attributed to a different chemical agents, after tests on the worker revealed an asthmatic response on exposure to GA (Gonnon, 1995). However, the mechanism of asthma unknown despite the presence of both irritants and sensitizers, there have been few reports of occupational asthma and other disorders among radiographers. A study have shown that up to 39.4% of radiographers have reported symptoms such as headache, sore throat, fatigue and eye irritation when processing films (Hewitt, 1993). The case studies also have shown that allergic type respiratory disorders are a frequent occurrence (Hewitt, 1993). These may have been caused by GA in the developer solution. Hewitt (1993) also, have shown that exposure to GA, acetic acid and SO_2 in film processing rooms have been associated with skin symptoms and decrements in pulmonary function (9). Usually, radiographers in the wet x-ray processing, have potential exposure to a mixture of many chemical agents including sensitizers and irritants such as GA, acetic acid and SO_2. Previous studies indicated that GA is a sensitizers and can cause asthma and respiratory symptoms (Smedley *et al*., 1996; Chan-Yeung *et al*., 1993). Most field-based study in the radiology department, indicated that acetic acid acting alone has been shown to cause reactive airway dysfunction syndrome (Kern, 1991), but it is also possible that the mixture of sensitizers and irritants chemicals could contributed to heightened sensitivity, or to other non-asthmatic symptoms. During the coarse of study, we have not odors related to chemicals in the darkrooms, thus lack of odor there is not an indicator of low exposure. With regards to this subject, Ruth (1986), reported that several substances such as GA and acetic acid have a low odor thresholds and irritation levels. The odor TLV for GA and acetic acid has been reported as 0.16 mg m^{-3} and 2.5 to 12.5 mg m^{-3}, respectively (ACGIH, 1997). In this study, the concentrations of GA at each darkroom have measured by area sampling. The result indicated that the concentration of GA were approximately five times higher than those taken by personal sampling. The average GA concentrations obtained by area sampling in this study seemed to be higher than those reported by other researchers (Scobbie *et al*., 1996; Gannon *et al*., 1995).

Volume of darkroom: In the present study, relationship between volume of darkroom and exposure to GA, indicated that greater darkroom volume was associated with lower exposure to GA (Table 5) and this is a sound reason for considering the dimension of darkrooms in the hospitals. Thus, it would appear that in the case, the highest risk of GA exposures are found in small size of darkrooms.

Effects of control methods: The advantage of engineering controls such as Local Exhaust Ventilation (LEV) can be seen indirectly by comparing our results with those of similar studies and directly from reports that have investigated the direct effects of control methods (Teschke *et al*., 2002; Lienster *et al*., 1992). A film processor modernization program that incorporated LEV reduced GA and acetic acid levels by up to 50%. Sulfur dioxide is a by-product of the drying process and is not controlled by current LEV design; other locations in processor rooms that do not normally have LEV include the floor drains to which processor chemicals are discharged and the tanks in which the developer and fixer chemicals are mixed and stored. With regard to the lack of LEV in the hospitals in this study, exposure to air pollutants in radiographic film processing may also be controlled by providing workers with respiratory protection.

Study limitation: There are some limitation to this study, particularly related to analytical difficulties in monitoring of low air concentrations. First, the adoption by ACGIH of TLV-ceiling of 0.2 mg m^{-3} may be problem for wet x-ray processing using GA in the absence of LEV. Second, with regards to analytical difficulties and limits of detection of the exposure monitoring methods, the methods of this study were unable to detect exposures such as GA, in more than 40-50% of the personal measurements. Third, this study focused on the GA, acetic acid and SO_2 exposures and does not measured for other exposure such as potassium hydroxide, hydroquinone and formaldehyde. In addition, with regard to places of exposure sample (TUMS hospitals) it is not clear whether the results can be generalized to other governmental and private hospitals in Tehran area.

CONCLUSIONS

In conclusion, exposure to GA, acetic acid and SO_2 were generally higher this study in a developing country than in similar operations in developed countries. This may be attributed in part to the fact that the wet x-ray machine are often imported and assembled without application of adequate engineering controls such as local exhaust ventilation hoods on the processes. Improvements in digital imaging systems to reduce the time, health risks and environmental compliance issues are strongly suggested. The use of personal protective equipments is also recommended to provide additional protection.

ACKNOWLEDGMENTS

The authors expresses gratitude to Seyed Jamaleddin Shahtaheri Ph.D, Mostapha Hosseini Ph.D for their analytical and biostatistics support; to Sayde-Someh and Ms. Divani for their technical help in air sampling and data collection. The authors also thank the hospital managements for their cooperation and the radiographers for their participation. This work was funded in part by the School of Public Health, Tehran University of Medical Sciences, Iran.

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