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Field Report

Biological monitoring for exposure assessment of volatile organic compounds by Korean firefighters at the fire site

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Abstract: The VOCs and metabolites in urine for exposed VOCs were evaluated for firefighters who participated in the actual fire fighting to determine whether firefighters were exposed to hazardous chemicals, which is the basic data on cancer risk of firefighters. When the fire extinguishing time is long, the concentration of benzene, PHEMA, and toluene among VOCs and metabolites in the case of fire suppression, rescue, and fire investigation work, which is estimated that the exposure of hazardous substances generated from the fire site at the time of fire suppression was large, significantly increased. In the case where the number of urination is 2 or less, the concentration of TZCA, toluene, and benzene among VOCs and metabolites was significantly increased compared to the number of urinating more than 2 times. In the concentration of VOCs and metabolites in urine corrected with creatinine, the concentrations of toluene and PHEMA in urine were significantly higher. The concentration of PHEMA in urine was higher in the group who participated in the fire suppression for more than 11 hours (long time) than the group who participated in the fire suppression for a short time.

Key words: Biological monitoring, Exposure assessment, Volatile organic compound, Metabolite, Firefighter

Introduction

Firefighters are exposed to various hazardous factors such as noise, particulate matters (PM), heavy metals, aldehydes, volatile organic compounds (VOCs), Polycyclic aromatic hydrocarbons (PAHs), acidic substances and gaseous pollutants during fire extinguishing and at the residual cleanup sites[1–5].

In the epidemiological study on cancer of firefighters in Korea, when the firefighters were compared with the general population, the risk of cancer was 0.97 (0.90~1.08 at 95% confidence interval) times for all cancers and 1.81(1.12~2.76 at 95% confidence interval) times for non-Hodgkin's lymphoma (NHL), which was significantly higher than that of the general population[6]. In a study in-

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volving firefighters in five Nordic countries, the incidence rates of all cancers and NHL were 1.06 (1.02~1.11 at 95% confidence interval) times and 1.04 times (95% confidence interval 0.83–1.29), respectively, compared to the general population[7]. Meta-analysis studies by LeMaster *et al.* (2006)[8] and IARC (2010)[9] reported that the NHL incidence rates of firefighters were 1.51 times and 1.21 times higher than that of the general population, respectively.

Firefighters can be exposed to a variety of chemical hazards during fire fighting, and the risk of developing cancer from shift work can also increase. In general, firefighters' exposure to carcinogens is recognized, but the International Agency for Research on Cancer (IARC) still classifies firefighters as a group 2B with cancer risk[9].

Since fires are unspecified and unexpected, there are many studies that are evaluated during simulated fires or fire drills and firefighters wear personal protective equipment to extinguish fires, there are limitations in evaluating their actual exposure. For this reason, firefighters' exposure assessment for hazardous substances is mainly conducted through biological monitoring that analyzes metabolites of PAHs and VOCs in urine[10, 11].

Because it has been reported that PAHs are detected in firefighters' fire suits or monitoring of skin exposure, and the PAHs concentration increases after fire fighting[4, 7, 11, 12], even if firefighters wear respirators during fire fighting, there is a possibility that they are exposed to hazardous substances through skin absorption in addition to the inhalation.

Thus, this study was carried out for evaluating VOCs and metabolites in urine in order to quantify the exposure level of hazardous substances of Korean firefighters who participated in fire fighting at the actual fire site.

Methods

Subject

This study was approved by the institutional review board of the Hallym University Sacred Heart University Hospital and Wonju Severance Christian Hospital (HALLYM 2019-05-005-001 and CR318064). Before the start of the study, we explained the procedure, purpose, and risks to all participants and obtained written informed consent.

In order to inquire the job details of each firefighter who participated in the fire suppression, the gender, current department, job at the time of the fire suppression, the time involved in the fire suppression, the distance from the fire site where the job was performed, and the type of protective equipment to be worn, etc. were surveyed using the self-filled questionnaire. After the fire suppression was completed, urine was collected for the analysis of VOCs and their metabolites in vivo by firefighters.

Urine sample collection

The firefighters' urine samples were collected 7 hours after the fire was extinguished (hereinafter, marked as "after fire fighting"), and 3 weeks later the same firefighters' urine samples were collected again. Approximately 10 ml of urine was collected in a polypropylene tube and stored frozen at −20°C until analysis.

Analysis of volatile organic compounds and their metabolites in urine

Thiazolidine-4-carboxylic acid (TZCA) in urine, a formaldehyde metabolite, was analyzed by derivatizing ethylchloroformate and methyl alcohol/pyridine solution (4:1, v/v) according to the method of Shin *et al.* (2007)[12]. The analysis equipment was gas chromatography (Agilent 689A, Palo Alto, CA, USA)-mass spectrometer (5975 MSD), the electron energy used for ionization was 70 eV, and quantitative analysis was performed by the selected ion-monitoring (SIM) method.

The volatile organic compounds (Toluene, Benzene, Ethylbenzene, Styrene and p-Isopropyltoluene) in urine were analyzed by gas chromatography (Agilent 689A, Palo Alto, CA, USA) connected to a headspace device-using a mass spectrometer (5975 MSD).

Analysis of m-cresol, phenol, 2-phenyl ethanol and 4-methylbenzyl alcohol(4-MBA) which are metabolites of toluene, benzene, ethylbenzene and xylene in urine, respectively, was performed with reference to the NIOSH method #8321 (NIOSH, 2016). According to the method, Methyl-t-butyl ether (MTBE) extracted by the liquid/liquid extraction pretreatment method was analyzed using gas chromatography (Agilent 689A, Palo Alto, CA, USA)-mass spectrometer (5975 MSD).

S-benzylmercapturic acid (BMA), S-phenylmercapturic acid(PMA) and N-acetyl-S-(1-phenyl-2-hydroxyethyl-L-cysteine+N-acetyl-S-(2-phenyl-2-hydroxyethyl)-L-cysteine(PHEMA) which are metabolites of toluene, benzene and styrene in urine, respectively, were analyzed according to the NHANES 2011-2012 Laboratory Method[8] and the Manual of Analytical Method #8326[14]. After pretreated with the solid-phase extraction method, they were quantified by using the directly coupled High-Performance Liquid Chromatography (Agilent 1200 Series LC system (Agilent, Santa Clara, CA, USA)) - Tandem Mass Spectrometry (Agilent 6460 Series Triple Quadrupole instrument (HPLC/MS/MS)). Finally, the creatinine analysis was performed to correct metabolites in urine.

Data analysis

The IBM Statistics SPSS 25.0 used for statistical analysis of the measured data. First, the normality distribution of the analysis data was tested to confirm the significance of the increase in the concentration of VOCs and metabolites in urine after fire suppression and 3 weeks after fire suppression. When the normality distribution was verified, the paired *t-test* was performed whereas the Mann-Whitney U test was applied for analysis data for which the normality was not proven.

Results

General characteristics and fire fighting situation

Table 1 presents the general characteristics of firefighters participating in the survey and the situation at the time of fire fighting. The number of study subjects who participated in the survey was 34 and the gender was 31 males and 3 females. The current tasks of the subjects were 9 firefighters, 8 first aid workers, 5 rescuers, 7 drivers, 4 administrative and office workers, and 1 fire inspector. The work at the time of fire extinguishing consisted of 10 firefighters, 1 on-site commander, 2 rescuers, 6 first aid workers, 6 drivers, 1 fire investigation, 6 on-site support, and 2 unanswered. The number of times they participated in the fire suppression was 12 hours, with 15 persons being the most, followed by 9 persons in 4 hours, 7 persons in 5 hours, 2 persons in 11 hours, and 1 person in 6 hours, respectively. While participating in the fire suppression, firefighters who participated in the suppression at a distance of less than 50m from the fire site were the most with 20 persons, 4 persons from 50m to less than 100m, 6 persons from 100m to less than 200m, and 4 persons over 200m, respectively. The type of protective equipment worn at the time of fire extinguishing was unworn by 13 persons, and among the study subjects, 10 persons were wearing self-contained breathing apparatus (SCBA), 8 persons for cotton masks, 1 person each for gas and dust masks, particulate filter masks, and others.

Concentrations of volatile organic compounds and metabolites in uncorrected urine

As indicated in Table 2, the concentrations of VOCs and metabolites in urine was compared between firefighters after fire extinguishing as the exposed group and 3 weeks later as the non-exposed group after fire extinguishing. The toluene concentration in urine after fire suppression was significantly higher than 3 weeks after fire suppression (GM : 0.423 vs 0.237μg/ℓ) (p<0.05). The concentration of PHEMA, a metabolite of styrene in urine, was significantly higher after fire suppression than after 3 weeks (GM : 5.202 vs 1.138μg/ℓ) (p<0.05). Although not statistically significant, the concentrations of TZCA, m-Cresol, BMA, Benzene, Phenol, Ethylbenzene, 4-MBA, Styrene, and p-Isopropyltoluene in urine were higher than those after 3 weeks after fire suppression (p>0.05). On the other hand, the urine concentrations of PMA and 2-Phenylethanol were higher after 3 weeks than after the fire suppression, but were not statistically significant (p>0.05).

Urine collected from firefighters after fire fighting was divided into groups with less than 6 hours (short time) participating in fire suppression and groups with more than 11 hours (long time) and compared. As a result, the concentration of benzene and PHEMA in urine were significantly higher for a long time than for a short time (p<0.05). Although not statistically significant, the concentrations of TZCA, Toluene, m-Cresol, BMA, Phenol, Ethylbenzene, 4-MBA, and Styrene in urine were higher for a long time than for a short time (p>0.05), except for 2-Phenylethanol and p-Isopropyltoluene.

As a result of comparing the group involved in fire extinguishing/rescue/inspection work that would have been relatively high exposed to VOCs with the group participating in other work depending on the work at the time of fire suppression, the concentration of PHEMA in the urine of the group that did fire extinguishing/rescue/investigation work was significantly higher than that of the other group (GM : 11.787 vs 3.583μg/ℓ) (p<0.05).

When comparing the group with a distance of less than 50m and more than 50m from the location where the fire was extinguished, urine PHEMA concentrations within 50m were significantly higher than those in the group exceeding 50m (GM : 8.198 vs 3.388μg/ℓ) (p<0.05).

As a result of comparing the group with two or less urine times and the group with three or more times before urine collection, the concentration of TZCA in urine for two or less urine times was significantly higher than the concentration of more than 3 times (GM : 0.574 vs 0.301 mg/ℓ). Also in the case of toluene and benzene, concentrations of 2 or less urine times were significantly higher than those of 3 or more times (GM : 0.553 vs 0.363 μg/ℓ and GM : 0.390 vs 0.080 μg/ℓ, respectively) (p<0.05).

In the correlation analysis between urine frequency and metabolite concentration (Table 3), the urine frequency showed significantly negative correlation with the concen-

Table 1. General characteristics of subjects

Classification		No. of respondent	Percent (%)
Gender	Male	31	91.20
	Female	3	8.80
Current task	Fire extinguishing	9	26.50
	First aid	8	23.50
	Rescue	5	14.70
	Driving	7	20.60
	Administrative affairs	4	11.80
	Fire inspection	1	2.90
Work at the time of fire extinguishing	Fire extinguishing	10	29.40
	Field command	1	2.90
	Rescue	2	5.90
	First aid	6	17.60
	Driving	6	17.60
	Fire inspection	1	2.90
	On-site support	6	17.60
	unanswered	2	5.90
Participation time in extinguishing fire	4 hours	9	26.50
	5 hours	7	20.60
	6 hours	1	2.90
	11 hours	2	5.90
	12 hours	15	44.10
Distance to the fire site when performing duty	Less than 50m	20	58.80
	50m – 100m	4	11.80
	100m – 200m	6	17.60
	200m or more	4	11.80
Type of protective equipment	SCBA	10	29.40
	Gas and dust mask	1	2.90
	Particulate filter mask	1	2.90
	Cotton mask	8	23.50
	Others	1	2.90
	Not worn	13	38.20

trations of toluene, ethylbenzene and styrene in urine. In the regression analysis (Table 4), the concentration of metabolites tended to decrease as the urine frequency increased, but this was not significant ($p>0.05$).

Concentrations of volatile organic compounds and metabolites in urine corrected with creatinine

Table 5 presents the concentrations of VOCs and metabolites in urine corrected with creatinine between firefighters after fire extinguishing as the exposed group and 3 weeks later as the non-exposed group after fire extinguishing. The concentrations of toluene(GM : 0.336 vs 0.191μg/g creatinine), m-Cresol(GM : 2.377 vs 1.308μg/g creatinine) and PHEMA(GM : 5.020 vs 0.990μg/g creatinine) immediately

Table 2. Summary of urinary VOCs and metabolite concentrations (Geometric Mean : GM)

Metabolite (Unit)	Immediately after fire extinguishing	3 weeks after fire extinguishing	Extinguishing time		Task		Distance from fire site		Urine frequency	
			Short time (n=12)	Long time (n=7)	Others (n=11)	Extinguishment / Rescue / Inspection (n=7)	Over 50m (N=6)	Within 50m (N=13)	3 or more (N=12)	2 or less (N=7)
TZCA (mg/L)	0.382	0.350	0.340	0.466	0.444	0.313	0.272	0.447	**0.301‡**	**0.574**
Toluene (μg/L)	**0.423***	**0.237**	0.395	0.477	0.424	0.464	0.398	0.436	**0.363***	**0.553**
m-Cresol (μg/L)	2.573	1.679	1.663	4.517	1.264	4.452	1.018	3.573	1.622	4.716
BMA (μg/L)	6.575	6.328	6.172	7.328	4.196	10.904	4.395	7.918	6.043	7.598
Benzene (μg/L)	0.149	0.092	**0.086‡**	**0.341**	0.137	0.113	0.128	0.151	**0.080***	**0.390**
Phenol (μg/L)	241.061	293.396	193.378	392.429	207.653	323.447	289.735	234.888	250.094	252.511
PMA (μg/L)	0.158	0.248	0.135	0.206	0.160	0.174	0.096	0.198	0.163	0.149
Ethylbenzene (μg/L)	0.094	0.071	0.079	0.121	0.080	0.095	0.071	0.105	0.071	0.148
2-Phenylethanol (μg/L)	126.314	133.127	135.981	115.748	131.871	135.522	140.257	122.913	134.630	117.746
4-MBA (μg/L)	0.973	0.707	1.141	0.707	0.707	1.607	0.707	1.100	1.141	0.707
Stylene (μg/L)	0.230	0.127	0.174	0.313	0.268	0.180	0.155	0.252	0.136	0.475
PHEMA (μg/L)	**6.202***	**1.168**	**3.669‡**	**15.249**	**3.583***	**11.787**	**3.388***	**8.198**	6.334	5.981
p-Isopropyltoluene (μg/L)	0.013	0.012	0.015	0.011	0.013	0.016	0.017	0.012	0.017	0.008

‡ : Mann Whitney U test, *, Paired *t-test*

‡,* : $p<0.05$

Table 3. Pearson's correlation between urine frequency and metabolite concentration in urine

(n=19)

Metabolite	r	*p*-value
TZCA (mg/L)	−0.378	0.110
Toluene (μg/L)	−0.780	0.000
m-Cresol (μg/L)	−0.266	0.271
BMA (μg/L)	−0.128	0.601
Benzene (μg/L)	−0.575	0.101
Phenol (μg/L)	0.109	0.657
PMA (μg/L)	0.077	0.754
Ethylbenzene (μg/L)	−0.571	0.011
2-Phenylethanol (μg/L)	0.186	0.447
4-MBA (μg/L)	0.044	0.857
Stylene (μg/L)	−0.576	0.010
PHEMA (μg/L)	−0.133	0.589
p-Isopropyltoluene (μg/L)	0.314	0.190

Table 4. Regression analysis of urine frequency and metabolite concentration in urine

Metabolite	B	SE	Beta	t	*p*-value
TZCA (mg/L)	0.439	1.442	0.148	0.304	0.773
Toluene (μg/L)	−6.837	5.879	−0.714	−1.163	0.297
m-Cresol (μg/L)	−0.010	0.021	−0.175	−0.456	0.667
BMA (μg/L)	−0.023	0.133	−0.175	−0.175	0.868
Benzene (μg/L)	0.103	4.363	0.027	0.024	0.982
Phenol (μg/L)	0.000	0.001	0.155	0.408	0.700
PMA (μg/L)	−0.473	1.954	−0.109	−0.242	0.819
Ethylbenzene (μg/L)	−2.839	9.902	−0.294	−0.287	0.786
2-Phenylethanol (μg/L)	0.003	0.013	0.093	0.247	0.815
4-MBA (μg/L)	0.006	0.024	0.245	0.265	0.801
Stylene (μg/L)	0.017	1.057	0.013	0.016	0.988
PHEMA (μg/L)	0.036	0.055	0.250	0.648	0.546
p-Isopropyltoluene (μg/L)	−3.593	17.301	−0.089	−0.208	0.844

after fire suppression were significantly higher than 3 weeks after fire suppression (GM : 0.423 vs 0.237μg/ℓ) (p<0.05).

As a result of dividing the group with less than 6 hours (short time) and the group with more than 11 hours (short time) in terms of participation time in the fire suppression, the concentration of PHEMA in urine was higher for a long time than for a short time (GM : 3.622 vs 9.749 μg/g creatinine) (p<0.05).

There was no significant difference in the comparison of the concentrations of VOCs and metabolites in the urine between the group that did fire suppression/rescue/investigation work and the other groups (p>0.05) and between group with a distance of less than 50m from the location where they worked at the time of fire fighting and group with a distance of more than 50m (p>0.05).

The concentration of benzene (GM : 0.282 vs 0.073 μg/g creatinine) in urine was significantly higher in the group with urine frequency of 2 or less than 3 or more (p<0.05). In the analysis of correlation between urine frequency and metabolite concentration, urine frequency showed a significant negative correlation with Benzene and Styrene concentrations in urine (p<0.05) (Table 6). In the regression analysis, as the frequency of urine increased the concentration of metabolites in urine tended to decrease, but it was not statistically significant (Table 7).

Table 5. Summary of creatinine-adjusted urinary VOCs and metabolite concentrations (Geometric Mean : GM)

Metabolite (Unit)	Immediately after fire extinguishing	3 weeks after fire extinguishing	Extinguishing time		Task		Distance from fire site		Urine frequency	
			Short time (n=12)	Long time (n=7)	Others (n=11)	Extinguishment/ Rescue / Inspection (n=7)	Over 50m (N=6)	Within 50m (N=13)	3 or more (N=12)	2 or less (N=7)
TZCA (mg/gCr)	0.296	0.319	0.336	0.298	0.515	0.177	0.263	0.352	0.277	0.415
Toluene (μg/gCr)	**0.336***	**0.191**	0.390	0.305	0.475	0.248	0.386	0.344	0.333	0.400
m-Cresol (μg/gCr)	2.377*	1.308	1.642	2.888	1.466	2.523	0.987	2.815	1.489	3.413
BMA (μg/gCr)	5.642	5.463	6.091	4.685	4.867	6.180	4.261	6.237	5.548	5.499
Benzene (μg/gCr)	0.124	0.077	0.085	0.218	0.159	0.064	0.124	0.119	**0.073‡**	**0.282**
Phenol (μg/gCr)	215.367	232.337	190.862	250.882	240.885	183.314	280.871	185.021	229.614	182.746
PMA (μg/gCr)	0.123	0.216	0.133	0.132	0.185	0.099	0.093	0.156	0.150	0.108
Ethylbenzene (μg/gCr)	0.078	0.058	0.078	0.077	0.093	0.054	0.069	0.083	0.065	0.107
2-Phenylethanol (μg/gCr)	99.892	107.013	134.212	73.998	143.757	75.780	135.967	96.819	123.606	85.215
4-MBA (μg/gCr)	0.808	0.578	1.127	0.452	0.820	0.911	0.685	0.867	1.048	0.512
Stylene (μg/gCr)	0.212	0.101	0.171	0.200	0.311	0.102	0.150	0.198	0.125	0.344
PHEMA (μg/gCr)	5.020*	0.990	**3.622***	**9.749**	4.156	6.680	3.285	6.457	5.816	4.329
p-Isopropyltoluene (μg/gCr)	0.010	0.010	0.015	0.007	0.015	0.009	0.017	0.009	0.016	0.006

‡ : Mann Whitney U test, *, Paired *t-test*, ‡,* : p<0.05

Table 6. Pearson's correlation between urine frequency and metabolite concentration in creatinine-adjusted urine

(n=19)

Metabolite	r	*p*-value
TZCA (mg/gCr)	−0.257	0.289
Toluene (μg/gCr)	−0.156	0.525
m-Cresol (μg/gCr)	−0.224	0.356
BMA (μg/gCr)	−0.108	0.941
Benzene (μg/gCr)	−0.539	0.017
Phenol (μg/gCr)	0.240	0.322
PMA (μg/gCr)	0.118	0.631
Ethylbenzene (μg/gCr)	−0.366	0.123
2-Phenylethanol (μg/gCr)	0.209	0.389
4-MBA (μg/gCr)	0.046	0.852
Stylene (μg/gCr)	−0.470	0.042
PHEMA (μg/gCr)	0.153	0.531
p-Isopropyltoluene (μg/gCr)	0.310	0.197

Table 7. Regression analysis of urine frequency and metabolite concentration in creatinine-adjusted urine

Metabolite	B	SE	Beta	t	*p*-value
TZCA (mg/gCr)	2.798	0.994	2.664	2.815	0.037
Toluene (μg/gCr)	−7.467	4.174	−2.803	−1.789	0.134
m-Cresol (μg/gCr)	−0.015	0.024	−0.158	−0.654	0.542
BMA (μg/gCr)	0.180	0.126	0.779	1.426	0.213
Benzene (μg/gCr)	−3.560	4.082	−0.647	−0.872	0.423
Phenol (μg/gCr)	0.002	0.001	0.369	1.525	0.188
PMA (μg/gCr)	−0.090	1.256	−0.030	−0.072	0.946
Ethylbenzene (μg/gCr)	1.515	7.790	0.200	0.194	0.853
2-Phenylethanol (μg/gCr)	0.016	0.015	1.292	1.019	0.355
4-MBA (μg/gCr)	−0.020	0.023	−0.501	−0.876	0.421
Stylene (μg/gCr)	−0.661	0.718	−0.863	−0.921	0.400
PHEMA (μg/gCr)	0.047	0.063	0.223	0.745	0.490
p-Isopropyltoluene (μg/gCr)	3.942	19.261	0.050	0.205	0.846

Discussion

This study analyzed VOCs and metabolites in the urine of firefighters participating in fire suppression in order to evaluate the exposure of VOCs during fire suppression. Biological monitoring is one of the exposure assessment methods that can evaluate various exposure routes such as skin absorption and ingestion as well as respiratory exposure of chemicals and abnormal exposure. In order to determine the exposure of VOCs, the concentrations of VOCs and metabolites in urine were compared after 3 weeks and immediately after the fire extinguishing with the same firefighters. Also, to compare the exposure to the situation at the time of fire extinguishing, the concentrations of VOCs and metabolites analyzed in urine collected from firefighters immediately after the fire extinguishing were compared in terms of extinguishing time, extinguishing task, distance from fire, and number of urine before urine collection.

Among VOCs and metabolites in uncorrected urine, the concentrations of toluene and PHEMA were higher in urine concentration immediately after fire suppression than in urine after 3 weeks, and those of toluene, m-Cresol, and PHEMA were higher in the case of creatinine correction. There was no significant difference in the concentrations of VOCs and metabolites in the urine between firefighters who conducted fire suppression within one week and those who did not conduct it to determine the effect of fire suppression on urine collected after 3 weeks. Therefore, during the fire fighting process, the firefighters can be judged to have been exposed to VOCs.

The value of 0.423μg/ℓ, the geometric mean concentration of toluene in the urine of firefighters analyzed Immediately after extinguishing the fire, was higher than the median toluene concentrations of 0.19μg/ℓ of non-smokers and 0.27μg/ℓ of smokers in urine among traffic police officers in the study conducted by Manini *et al.*(2008)[13] and lower than the median toluene concentration of 0.60μg/ℓ in urine of non-smokers among gas station employees reported by Campo *et al.* (2016)[14]. Toluene may be absorbed through the respiratory tract by taking off the SCBA depending on the firefighter's work situation, but considering the absorption through the skin, this value(0.423μg/ℓ) is considered to be relatively low. On the other hand, in the case of TZCA, a formaldehyde metabolite that was not statistically significant but showed an increasing trend, the firefighters would be exposed to formaldehyde during the fire fighting as the finding that the geometric mean concentration of TZCA in the urine of firefighters was 0.296mg/g creatinine immediately after extinguishing the fire was compared with the report that the mean concentrations of TZCA in the urine of the groups exposed to formaldehyde concentrations of 0.03 ppm and 0.18 ppm in the air were 0.097 mg/g creatinine, and 0.179 mg/g creatinine, respectively[15].

The concentration of PHEMA, a metabolite in the urine of uncorrected styrene, was significantly higher (p<0.05) in case of the fire suppression time of 11 hours or more (long time), conduction of fire suppression/rescue/investigation work, and the location where the fire was extinguished is within 50m of the fire site. As this study was conducted at one specific fire site, it is considered that the results obtained from this study cannot be generalized. The PHEMA, sum of N-acetyl-S-(1-phenyl-2-hydroxyethyl-L-cysteine(M1) and N-acetyl-S-(2-phenyl-2-hydroxyethyl)-L-cysteine(M2), is one of the urine metabolites of styrene and used as a urine index for low-concentration styrene exposure evaluation[16]. The geometric mean concentration of PHEMA in urine was 1,879.3mg/g creatinine when the average concentration in air of workers exposed to styrene was 112.7mg/m3[17]. This result is significantly different from the PHEMA geometric mean concentration of 5.020ug/g creatinine of urine immediately after fire suppression analyzed through this study. However, compared with the results of Alwis *et al.*(2012)[18], where the PHEMA concentration of the general public was less than the detection limit (0.7μg/ℓ), firefighters can have a possibility of exposure to styrene during the fire extinguishing process.

Urine is collected by a method of collecting temporary urine (spot urine sample) and since the urine concentration level and the amount of excretion vary, the method of correcting with creatinine is common. However, there are opinions that there are many variables that affect the excretion of creatinine in urine, so discussion on the suitability is necessary[15]. ACGIH (2013)[16] recommends the Biological Exposure Indices of Toluene in urine as 0.03mg/L without creatinine correction. Additional studies are needed to determine whether creatinine is corrected for accurate evaluation with spot urine samples in this study.

As a result of comparing the concentration of VOCs and metabolites according to the number of urine before sample collection, the concentrations of TZCA, toluene and benzene were significantly higher (p<0.05) in less than 2 times than 3 or more times before urine collection immediately after fire extinguishing and only benzene was significant (p<0.05) when calibrated with creatinine.

In the analysis of correlation between urine frequency and metabolite concentration, toluene, benzene, ethylbenzene, and styrene showed a statistically significant negative correlation, and it was found that the higher the urine frequency, the more the metabolite concentration tended to decrease. In biological monitoring, the timing of urine collection is important depending on the half-life of the substance. ACGIH (2013)[16] recommends that urine metabolites such as toluene, benzene and styrene, or non-metabolized substances, should be collected immediately after the end of exposure as far as possible. In this study, it is presumed that the concentration of metabolites decreased according to the number of urine collected after 7 hours elapsed immediately after the fire was extinguished. In order to accurately evaluate the exposure of VOCs according to fire suppression, it is considered appropriate to collect urine samples immediately after fire suppression and further research on this is also required.

There are several limitations in this study. At first, urine was collected 7 hours after fire extinguishing. The absolute values of exposure were relatively low. To compensate for this shortcoming, we compared the difference by urine frequency. Second, this study is that a single fire site was targeted and only some VOCs (7 substances) were biologically monitored. In addition, there are differences in hazardous substances that occur according to various circumstances such as the location of the fire site, the type of fire, and the type of fire material, and there may be differences in the exposure patterns of firefighters. Thus, it is necessary to continuously evaluate the exposure of various fire sites, including harmful factors related to carcinogenesis of firefighters, and to ensure active participation of firefighters in investigating exposure to hazardous substances caused by fire extinguishing. Finally, considering that 13 out of 34 firefighters who were engaged in the fire extinguishing process responded that they did not wear safety protection equipment, specialization and education in field-oriented health management to minimize exposure to hazardous chemicals should be systemized as soon as possible.

Conflict of Interest

The authors declare no competing financial interests.

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