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Oxidative Stress Biomarkers among Residents measured 6 years after the *Hebei Spirit* Oil Spill

허베이스피리트호 유류유출사고 6년 후 피해지역 주민의 산화손상지표 농도

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김 정 아

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Graduate School of Public Health
Seoul National University
Environmental Health Sciences Major

Jung-Ah Kim

Abstract

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Kim, Jung-Ah

Department of Environmental Health Sciences

Graduate School of Public Health

Seoul National University

In December 2007, the *Hebei Spirit* oil spill accident occurred on the west coast of South Korea. Among the local residents, a dose-response relationship between the exposure to crude oil and urinary oxidative stress biomarkers was reported previously, 1.5 years after the oil spill. The aim of this study was to examine possible longer term effects associated with the exposure to oil spill among the residents, six years after the oil spill, especially in terms of oxidative stress biomarkers.

The target subjects were recruited based on the location of their residence and were also classified by their history of clean-up activities following the oil spill. In the vicinity of the oil spill, i.e., within 20 km from the oil spill site, a total of 476 adults (grouped as 'Near'), and from the area beyond 20 km away from the spill site, 152 adults were recruited (grouped as 'Far') in 2014, respectivey. The participating adults were measured for 8-hydroxy-2-deoxyguanosine (8-OHdG) and malondialdehyde (MDA) levels in their 12-hour urine samples as indicators of oxidative DNA damage and lipid peroxidation, respectively. The subjects were also asked to fill the questionnaire. Multivariate general linear model was used to statistical analysis by SAS package (GLM procedure).

The geometric means (geometric standard deviation) of the urinary oxidative stress biomarkers measured in the study population were 5.31 (1.78) μg/g creatinine and 2.15 (1.71) μmol/g creatinine for urinary 8-OHdG and MDA levels, respectively. Duration of clean-up activities and the distance of residence from the oil spill site, showed significant association with both 8-OHdG and MDA levels, even after adjusting for sex, age, income, and creatinine corrected cotinine levels.

Even 6 years after the oil spill, positive associations between oxidative stress biomarkers and oil exposure were evident. While the present observation should be confirmed in other situations and populations, the results of this study suggest that the consequences of oil pollution may last for years. Health implication of this observation deserves further investigation.

Keywords : Environmental disaster, Oil exposure, Long-term health effect, Oil spill, Oxidative stress, MDA, 8-OHdG

Student Number : 2014-23396

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Abbreviations

1-OHP: 1-hydroxypyrene

8-OHdG: 8-hydroxy-2-deoxyguanosine

CV: coefficient of variation

ELISA: enzyme linked immunosorbent assay

FD: fluorescence detector

GM: geometric mean

GSD: geometric standard deviation

HPLC: high performance liquid chromatography

HSOS: *Hebei Spirit* Oil Spill

LOD: limit of detection

MDA: malondialdehyde

PAHs: polycyclic aromatic hydrocarbons

PTSD: post-traumatic stress disorder

VOCs: volatile organic compounds

Chapter 1. Introduction

1.1. Study Background

Oil spills occurring near coastal area have caused serious ecological consequences worldwide (Barron, 2012; Peterson et al., 2003). Oil spills near heavily populated coastline are less common, but once happen, it could cause adverse health outcomes among the residents along with clean-up workers (D'Andrea and Reddy, 2014; Perez-Cadahia et al., 2007). Environmental health research on disasters like oil spill is difficult as it occurs only in specific periods of time and locations (IJzermans et al., 2005). However, it is possible that such disaster may cause not only biological but also psychological stresses in both short and long term periods (Galea, 2007).

The *Hebei Spirit* Oil Spill (HSOS) accident occurred in December 2007 in the West Sea of Korea, and is one of the worst oil spill episodes in Korea. More than 10,000 kℓ of crude oil spilled into the sea. The oil spill site was about 10 km away from the beach and residential area of Taean county. Shortly after the accident, most of residents, who had been involved in fishery or tourism for living, participated in clean-up activities along the contaminated coastline (Ha et al., 2012). These people did not wear proper protective equipment during the remediation efforts, and consequently were exposed to various oil related chemicals.

Crude oil is composed of volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and to lesser extent, heavy metals (Ha et al., 2012). During the first few days after the accident, the levels of VOCs in Taean area were modeled to be much higher than indoor environmental criteria (Kim et al., 2012).

Reports of acute somatic symptoms after clean−up work also support adverse health effects of oil pollution following short−term exposure.

Long-term health effects among clean−up workers and residents of affected area are of concern. Environmental health surveys conducted for local residents in 1.5 years after the spill showed that oil exposure from prolonged clean-up activity was likely associated with increased levels of oxidative stress, and also showed significant positive associations between levels of oxidative stress and 1-hydroxypyrene (1-OHP) which is metabolite of PAHs (Noh et al., 2015).

1.2. Purpose of Research

The aim of this study is to follow−up consequences of long−term health effects of oil spill among the clean−up worker and residents of the affected area. For this purpose, residents with different history of clean-up works and residence with varying distance from the spill location were recruited 6 years after the oil spill and compared for urinary oxidative stress markers such as malondialdehyde (MDA) and 8-hydroxy-2-deoxyguanosine (8-OHdG). The results of this study will help better understand long-term health consequences of oil spill, and prepare contingency planning for such accidents.

Chapter 2. Materials and Methods

2.1. Study Population

The study populations were chosen based on the administrative districts of the most severely affected district as case, and less affected area as control, within Taean county. Subjects were first contacted by telephone, and asked for participation. From the vicinity of the oil spill site, i.e., seven coastal villages, 615 adults out of the total adult population of 4046 (Taean−gun, 2014) agreed to participate. From the less affected area (control), 187 adults participated voluntarily. Therefore, a total of 802 individuals participated in health monitoring and questionnaire survey in 2014. Among them, 628 residents were measured for urinary stress biomarkers, and were assessed in the present study. This study was approved by Institutional Review Board of Dankook University Hospital, Cheonan, Korea. Written informed consent was obtained from each participant before enrollment.

The study participants were classified into two groups of ‘Near’ and ‘Far’ based on the location of their residence; within 20 km from the spill site as ‘Near’ (n=476) and beyond 20 km as ‘Far’ (n=152). The area of residence for ‘Near’ and ‘Far’ groups are shown in Figure 1.

Figure 1. Study area showing 'Near' area most affected by the spill, and 'Far' area less affected, within Taean county.

2.2. Questionnaire

Demographic information and parameters that may influence oil exposure were obtained from questionnaire. Self-reported questionnaire was conducted, but in case when the subject was illiterate or disabled, face to face interview was conducted. History of clean-up works was asked. Distance from the spill site was calculated using geographic information system.

2.3. Measurement of Urinary Biomarkers

- **Collection of urine samples**

Participants were asked to collect all the urines during the 12 hours period before the health examination in the morning. Detailed instructions and a collection bag were provided in advance. Urine was then transferred to 15 ml conical polypropylene tubes and stored in a freezer at −20 °C and delivered to the Department of Preventive Medicine, College of Medicine, Chungbuk National University, for analyses of biomarkers.

- **Urinary measurements**

Urinary MDA was measured using high performance liquid chromatography with a fluorescence detector (HPLC/FD) following Agarwal and Chase (2002). The limit of detection (LOD) of urinary MDA was 0.07 μmol/L and the intra-assay coefficient of variation (CV) for the pooled urine sample was 5.25%. Urinary 8-OHdG was analyzed by a commercial enzyme linked immunosorbent assay (ELISA) kit following the manufacturer instruction (Japan Institute for the Control of Aging, Kyoto, Japan). The LOD of urinary 8-

OHdG was 0.19 μg/L and the intra−assay CV was 4.18%. Urinary cotinine was measured using an ELISA kit following the manufacturer instruction (Calbiotech, Spring Valley, CA, USA) to estimate the exposure level to tobacco smoke. Urinary creatinine levels were determined using the Creatinine−wako test (Lindback and Bergman, 1989), and were used to adjust for the urinary MDA, 8-OHdG and cotinine concentrations to control for the variability in urine dilution. The LOD of urinary creatinine was 0.072 mg/dL.

2.4. Statistical Analysis

Statistical analyses were performed using SAS package (version 9.4). The association between the surrogates of oil spill exposure and oxidative stress biomarkers were assessed by a multiple generalized linear regression model based on the PROC GLM procedure of the SAS program. Several covariates were added in the model. Geometric mean (GM) and geometric standard deviation (GSD) and all statistical models were calculated for log−transformed urinary biomarkers, because the concentrations of MDA and 8-OHdG were not normally distributed.

Chapter 3. Results

3.1. Population Characteristics

About three quarters of the study population reside in 'Near' area (n=47, 75.8%), and the rest in 'Far' area (Table 1). The mean age of study subjects was 64.4 years with range of 24-85 years. Over 60 years were 71.4% among total subjects. Current smokers were 9.6% (60 out of 628), and smoking status and levels of urinary cotinine were not different (data not shown) between 'Near' and 'Far' area. Almost half of the individuals (292 out of 628, 46.5%) were classified lowest monthly household income which is less than 500 thousand Korean won per a month. Study subjects in 'Near' area include more males ($p=0.03$), more affluent in terms of monthly income ($p<0.001$).

Table 1. Demographic characteristics of study population, N (%).

	Total	Near [a]	Far [b]	*p*-value
Total	628 (100.0)	476 (100.0)	152 (100.0)	
Sex				
Female	343 (54.6)	248 (52.1)	95 (62.5)	0.0250
Male	285 (45.4)	228 (47.9)	57 (37.5)	
Age (years)				
< 60	180 (28.7)	144 (30.3)	36 (23.7)	
60-69	248 (39.5)	173 (36.3)	75 (49.3)	0.0169
≥ 70	200 (31.9)	159 (33.4)	41 (27.0)	
Smoking				
No	463 (73.7)	346 (72.7)	117 (77.0)	
Former	105 (16.7)	88 (18.5)	17 (11.2)	0.0796
Yes	60 (9.6)	42 (8.8)	18 (11.8)	
Monthly household income[†]				
< 50	292 (46.5)	194 (40.8)	98 (64.5)	
50-199	252 (40.1)	216 (45.4)	36 (23.7)	<0.0001
≥ 200	84 (13.4)	66 (13.9)	18 (11.8)	
Seafood intake[‡]				
≤ 1-3 times a month	205 (32.6)	161 (33.8)	44 (29.0)	0.2643
≥ 2-3 times a week	423 (67.4)	315 (66.2)	108 (71.1)	

[†] 10,000 Korean won.
[‡] Seafood intake one or more among 6 types (oyster, mania clam, blue crab, tiger prawn, small octopus, and laver).
[a] residence within 20 km from the oil spill site.
[b] residence beyond 20 km from the oil spill site.

3.2. Oil Spill related Characteristics of Study Population

The mean of clean-up duration of the study population was 114.1 days, with a range of 0 to 324.5 days (Table 2). Subject who did not participated in clean-up activities were 9.1% (15 out of 628). The average clean-up duration among 'Near' group was 150 days (range, 2.5 to 324.5 days), whereas the average clean-up duration among 'Far' group was significantly lessor, i.e., 3 days (range, 0 to 47 days). The means distance from the residence to the oil spill site were 15.4 km and 48.8 km among 'Near' and 'Far' group, respectively.

Table 2. Exposure characteristics of study population by duration of clean-up activities, and distance of residence from oil spill site.

	Total (n=628)	**Near [a] (n=476)**	**Far [b] (n=152)**	***p*-value**
Clean-up (days)				
Mean, SD	114.1 ± 76.9	149.6 ± 50.7	2.8 ± 6.0	<0.0001
50^{th}	129.0	147.5	2.5	
25^{th}, 75^{th}	21.5, 164.5	122.0, 172.5	0, 2.5	
Min, Max	0, 324.5	2.5, 324.5	0, 47.0	
Distance[†] (km)				
Mean, SD	23.5 ± 14.9	15.4 ± 1.7	48.8 ± 7.5	<0.0001
50^{th}	15.8	15.1	50.6	
25^{th}, 75^{th}	14.8, 19.3	14.5, 16.2	43.1, 53.3	
Min, Max	11.5, 62.7	11.5, 19.7	29.7, 62.7	

[†] Distance of residence from the oil spill site.
[a] residence within 20 km from the oil spill site.
[b] residence beyond 20 km from the oil spill site.

3.3. Levels of Urinary Oxidative Stress Biomarkers

GM of urinary MDA was 2.14 μmol/g creatinine, and urinary 8-OHdG was 5.31 μg/g creatinine (Table S1). Levels of urinary MDA and 8-OHdG were significantly higher in women than in men, and showed increasing trend by age. While no difference in oxidative stress markers were observed by smoking status, urinary MDA showed positive association with cotinine levels. Monthly household income was significant associated with levels of oxidative stress, but seafood intake showed no impact on both urinary MDA and 8-OHdG. Correlations between each factor were described in Table S2.

3.4. Associations with Urinary Oxidative Stress Biomarkers

In Table 5, GMs of urinary MDA and 8-OHdG by area group, quartiles of clean-up duration, and groups of distance from the residence to oil spill site are summarized. Crude geometric means and adjusted GM control for covariates were represented, respectively.

Levels of urinary MDA and 8-OHdG were higher among 'Near' group than 'Far' group (Table 5). Urinary 8-OHdG levels were significantly higher among 'Near' group in adjusted model, while MDA levels were significantly higher only in the unadjusted model. The similar trend was observed by the quartiles of clean-up duration. Levels of urinary MDA and 8-OHdG were significantly higher among Q3 (clean-up duration of 129-164.5 days) and Q4 (>164.5 days) than the reference (Q1, <21.5 days). Significant increase pattern was also observed in MDA by quartiles of clean-up activities in both unadjusted and adjusted model (p for trend < 0.05, Table 3). Results of analytical model after adjusting for covariates are shown in Figure 1.

When analyzed by the distance of residence from the oil spill site, the nearest group (11-15 km) showed significantly higher levels of urinary MDA and 8-OHdG than the 'Far' group (≥ 29 km). A significant distance dependent trends of urinary 8-OHdG (Figure 2). Urinary levels of MDA showed strong association with oil exposure in unadjusted model, whereas association between urinary levels of 8-OHdG and oil exposure in adjusted model was stronger than unadjusted model.

Table 3. Unadjusted and adjusted geometric means (95% CL) of oxidative stress biomarkers by oil exposure parameters.

	n	MDA (µmol/g creatinine)		8-OHdG (µg/g creatinine)	
		Unadjusted	**Adjusted**	**Unadjusted**	**Adjusted**
Area					
Far (controls) [a]	152	2.01 (1.85, 2.19)	1.99 (1.82, 2.18)	5.01 (4.57, 5.49)	4.71 (4.27, 5.20)
Near (exposed) [b]	476	2.19 (2.09, 2.30)*	2.15 (2.04, 2.26)	5.41 (5.14, 5.70)	5.31 (5.01, 5.62)**
p-value		0.0797	0.1443	0.1512	**0.0294**
Clean-up (days)					
Q1 (< 21.5)	155	2.01 (1.84, 2.18)	2.00 (1.83, 2.19)	5.01 (4.58, 5.48)	4.75 (4.31, 5.23)
Q2 (21.5-129.0)	154	2.07 (1.90, 2.25)	2.03 (1.86, 2.21)	5.07 (4.63, 5.56)	4.93 (4.50, 5.40)
Q3 (129.0-164.5)	160	2.29 (2.11, 2.49)**	2.23 (2.04, 2.43)*	5.70 (5.21, 6.23)**	5.54 (5.05, 6.07)**
Q4 (≥ 164.5)	159	2.24 (2.06, 2.43)*	2.19 (2.01, 2.39)	5.49 (5.02, 6.00)	5.48 (5.00, 6.02)**
p-trend		**0.0252**	**0.0498**	0.0576	**0.0082**
Distance (km) †					
Controls (≥ 29 km)	152	2.01 (1.85, 2.19)	1.99 (1.82, 2.18)	5.01 (4.58, 5.49)	4.72 (4.28, 5.20)
16-20 km	133	2.09 (1.91, 2.29)	2.04 (1.86, 2.24)	5.36 (4.86, 5.91)	5.23 (4.73, 5.78)
15-16 km	150	2.25 (2.06, 2.45)*	2.20 (2.01, 2.40)	5.03 (4.59, 5.52)	4.90 (4.46, 5.39)
11-15 km	193	2.23 (2.07, 2.40)*	2.18 (2.01, 2.35)	5.77 (5.32, 6.26)**	5.68 (5.23, 6.18)**
p-trend		**0.0477**	0.0760	0.0517	**0.0084**

Adjusted models control for sex (female, male), age (continuous), monthly household income (< 50, 50-199, ≥ 200), and creatinine corrected urinary cotinine level (Q1-Q4).

[a] Residence beyond 20 km from the oil spill site.

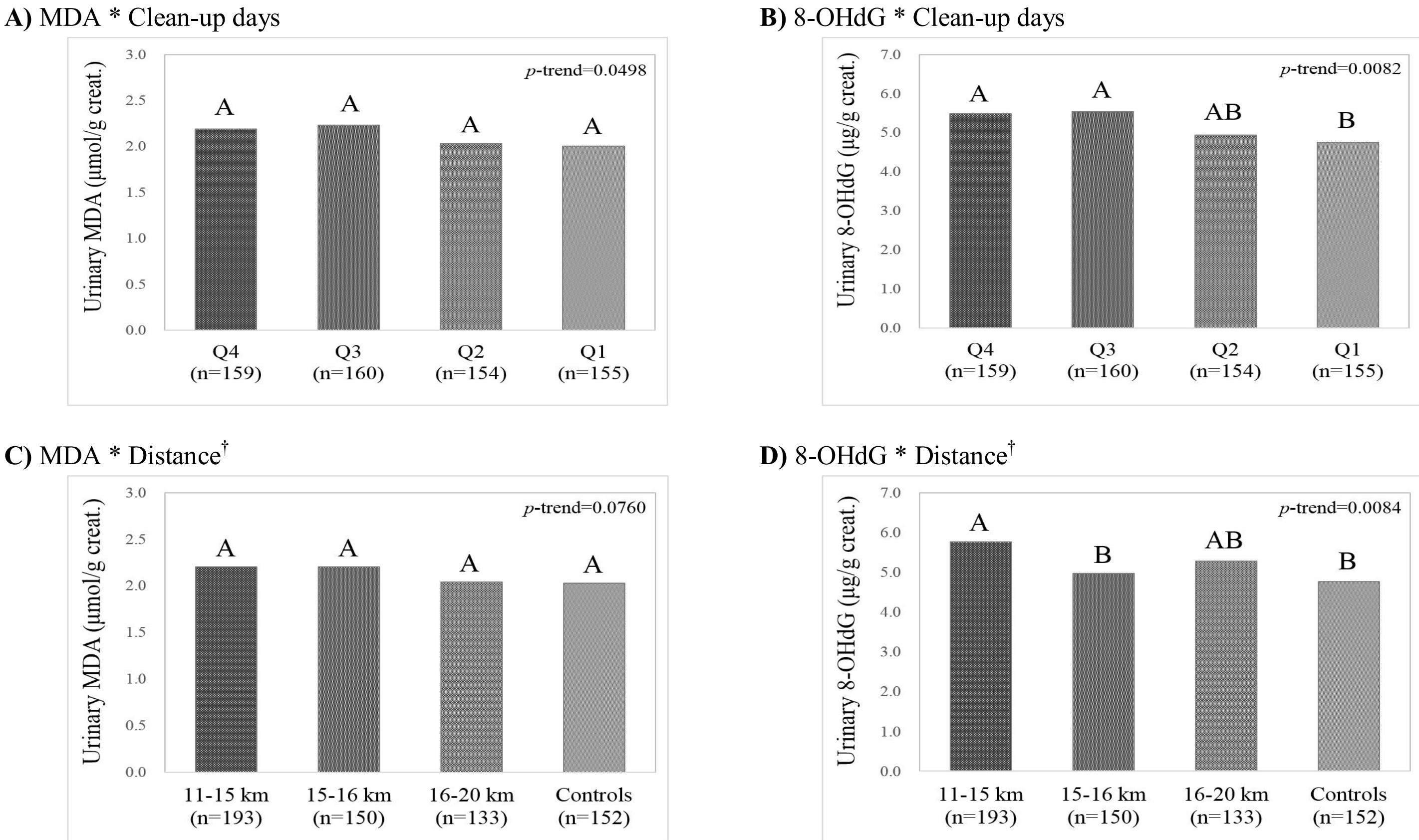
[b] Residence within 20 km from the oil spill site.

† Distance of residence from the oil spill site.

* *p*-value<0.1

** *p*-value<0.05

Figure 2. Levels of oxidative stress biomarkers by oil exposure parameters.



For clean-up days, Q1, Q2, Q3, and Q4 indicate <21.5 d, 21.5-129 d, 129-164.5 d, and ≥164.5 d, respectively. Geometric means are adjusted for sex (female, male), age (continuous), monthly household income (< 50, 50-199, ≥ 200), and creatinine corrected urinary cotinine level (Q1-Q4).

† Distance of residence from the oil spill site.

Chapter 4. Discussion

The observation of higher urinary oxidative stress biomarkers among the residents who have participated more clean-up activities or reside near the spill site, suggests that health impacts from oil exposure could persist for long time, up to 6 years and more. Similar observations have been reported for HSOS, but within shorter period of time after the spill. Among the same target population, urinary levels of MDA and 8-OHdG among residents measured at 1.5 years after HSOS (n=671) were positively associated with clean-up activities (Noh et al., 2015). In the same study, authors reported that the urinary oxidative stress markers were positively associated with urinary levels of 1-OHP which is a metabolite of pyrene.

Several other epidemiological studies also reported that oil spill accidents may cause lingering health damages. In a follow-up study of the *Prestige* oil spill in Spain, exposure to oil through clean-up activities might cause respiratory symptoms that could persist up to 5 years after the accident (Zock et al., 2012). Among the individuals who were exposed to the oil spill, persisted chromosome damage was observed after 6 years of the *Prestige* oil spill (Hildur et al., 2015).

However, there are also studies that suggest otherwise. In a follow-up survey conducted for local fishermen 6 years after the *Prestige* oil spill, greater damages during the follow-up period in lung function, oxidative stress and growth factors were observed among the non-exposed controls (n=57) than the exposed individuals (n=158) who are fishermen in heavily affected areas (Zock et al., 2014). In addition, no significant differences in the comet assay, the T-cell receptor mutation assay, and the cytokinesis-block micronucleus test were detected between local fisherman (n=54) and matched controls (n=50) at 7 years after the *Prestige* oil spill (Laffon et al., 2014). These observations may due to recovery after sufficient period of time.

When the urinary oxidative stress markers of the same set of subjects (n=628) were gleaned from the population participated in the baseline survey 1.5 years after the HSOS, the levels of urinary MDA and 8-OHdG tend to decrease over time, i.e., between 2009 and 2014, from 2.29 to 2.15 μmol/g creatinine for MDA, and 5.78 to 5.31 μg/g creatinine for 8-OHdG. This observation suggests that the causes of the oxidative stress among the residents of the study area have attenuated over time (Figure S1).

Nevertheless, levels of oxidative stress measured in year 2014 shows somewhat higher than the levels among general population. When urinary MDA levels measured by same method (HPLC/FD) were compared, GM of urinary MDA in the present study (n=628) was higher than in local residents (n=40) in residential area of Cheongwon, Korea with average age of 60.4 years (1.18 vs. 2.15 μmol/g creatinine) (Kim et al., 2008). Even the urinary MDA levels of 'Far' area residents (n=152) in the present study, i.e., average of 2.01 μmol/g creatinine, was higher than that of Choengwon county. In addition, the levels of 8-OHdG in this study were higher than the women (n=165) with a mean age of 64 years living near an abandoned metal mine (2.78 vs. 5.31 μg/g creatinine) (Choi et al., 2010), while were lower than those reported from 92 males with average age of 41 years in industrial complex (9.48 vs. 5.31 μg/g creatinine) (Kim et al., 2011).

After adjusting covariates such as sex, age, monthly income, and smoking status, which could influence the level of urinary oxidative stress markers, the association between history of clean-up activities and the distance between residence and the location of the spill remained significant. What would be underlying mechanisms that would possibly explain elevated oxidative stress biomarkers even at 6 years after the oil spill? One cannot rule out a possibility of remnants of oil pollution still present in various environmental matrices and therefore in the food chain, and cause oxidative stress among the residents. Along the affected coastline, elevated levels of PAHs have been observed (Yim et al., 2007), and various modes of toxicities such as dioxin-like toxicity, genotoxicity, and endocrine effects have been reported even several years after the spill (Ji et al., 2011; Kim et al., 2016). In addition, certain PAHs can remain in fat tissue (Lu et al., 2002; Moon et al., 2012), and may cause prolonged effects over time. Another possibility for the observed oxidative stress can be found from post-traumatic stress disorder (PTSD) among this study subject. PTSD prevalence increased among the residents in the area closer to the oil spill site. Prevalence of PTSD among residents in 'Near' and 'Far' area were 19.3% and 10.5%, respectively ($p=0.01$, Data not shown). A study for earthquake survivors reported that serum MDA levels from PTSD patients were significantly higher than healthy control (Atli et al., 2016). Finally, epigenetic changes that could be caused by PAHs exposure may explain the elevated oxidative stresses among the population with more clean-up workers. Reactive oxygen species may increase changes in DNA methylation profiles and/or histone modifications (Ziech et al., 2011). Due to such epigenetic changes, metabolic enzymes could be influenced (Bartsch et al., 1992; Fazili et al., 2010). Specific enzymes such as DNA repair gene promoters could be de−activated or hyper−activated by epigenetic pathways, and possibly result in elevated 8-OHdG levels.

While this study has intrinsic limitation as a cross−sectional observation, this study is unique in that the similar group of people were followed up for several years. It therefore warrants further confirmation in other populations living near oil spill over time.

Chapter 5. Conclusion

Even 6 years after the oil spill, urinary levels of oxidative stress biomarkers were significantly higher among the population with more clean-up activities or living in 'Near' area. While the levels of urinary oxidative stress markers decreased in 2014 compared to those measured in 2009, the levels observed in 2014 were still higher than those of general population. Such elevated oxidative stress levels may be explained by remnants of oil pollution in surrounding areas, possible consequences of PTSDs among the residents, and epigenetic modification. While further confirmation would be necessary in other situations, the results of this study suggest that the consequences of oil pollution may last for years. In an event of oil pollution, appropriate management policy and exposure mitigation measures should be developed to circumvent adverse health effects of oil pollution.

Supplements

Table S1. Geometric means of urinary oxidative stress biomarkers according to the general characteristics.

	N (%)	MDA (μmol/g creatinine)		8-OHdG (μg/g creatinine)	
		GM (GSD)	*p*-value	GM (GSD)	*p*-value
Total	628 (100.0)	2.14 (1.70)		5.31 (1.79)	
Sex					
Female	343 (54.6)	2.23 (1.77)	0.0663	5.64 (1.77)	**0.0022**
Male	285 (45.4)	2.05 (1.63)		4.90 (1.79)	
Age (years)					
< 60	180 (28.7)	1.99 (1.63)	0.1028	4.71 (1.75)	**0.0023**
60-69	248 (39.5)	2.18 (1.68)		5.42 (1.82)	
≥ 70	200 (31.9)	2.25 (1.80)		5.75 (1.73)	
Continuous			**0.0059**		**0.0004**
Smoking					
No	463 (73.7)	2.16 (1.73)	0.5258	5.31 (1.77)	0.9974
Former	105 (16.7)	2.16 (1.72)		5.31 (1.75)	
Yes	60 (9.6)	1.99 (1.48)		5.31 (1.88)	
Cotinine (μg/g creat.)					
Q1 (0.29-0.86)	157 (25)	1.86 (1.65)	**0.0014**	5.16 (1.86)	0.8670
Q2 (0.86-1.29)	157 (25)	2.20 (1.67)		5.42 (1.72)	
Q3 (1.29-2.06)	157 (25)	2.32 (1.77)		5.37 (1.68)	
Q4 (2.06-1256.44)	157 (25)	2.23 (1.70)		5.37 (1.84)	
Monthly household income[†]					
< 50	292 (46.5)	2.16 (1.79)	**0.0364**	5.81 (1.75)	**0.0009**
50-199	252 (40.1)	2.25 (1.63)		5.00 (1.77)	
≥ 200	84 (13.4)	1.88 (1.57)		4.66 (1.80)	
Seafood intake[‡]					
≤ 1-3 times a month	205 (32.6)	2.18 (1.70)	0.5678	5.21 (1.75)	0.5200
≥ 2-3 times a week	423 (67.4)	2.14 (1.72)		5.37 (1.79)	

[†] 10,000 Korean won.
[‡] Seafood intake one or more among 6 types (oyster, mania clam, blue crab, tiger prawn, small octopus, and laver)

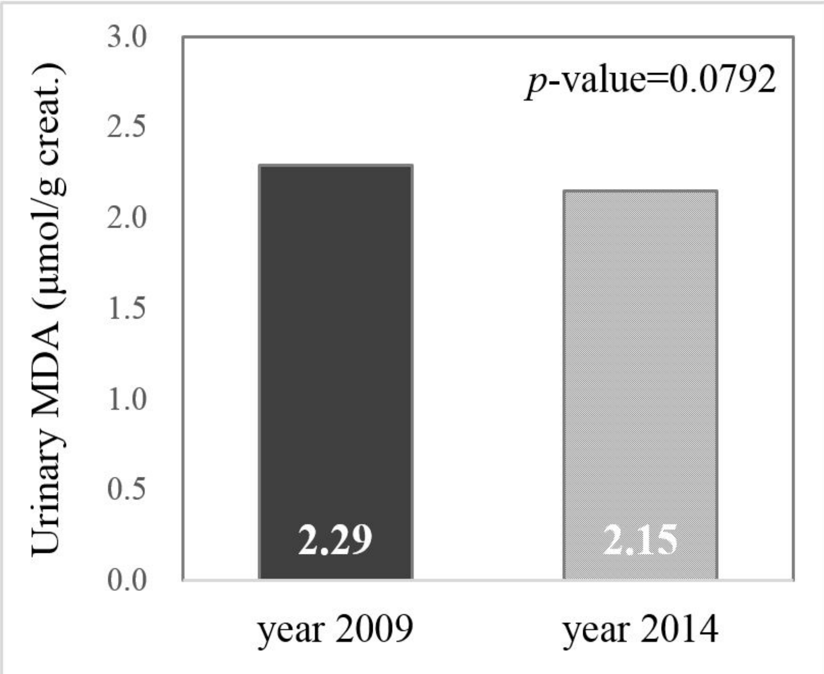
Table S2. Correlations between general characteristics.

	Correlation coefficient (*p*-value)			
	Sex [a]	**Age** [b]	**Cotinine** [c]	**Income** [d]
Sex [a]	1 (-)	0.11893 **(0.0028)**	-0.07009 (0.0793)	0.08413 **(0.0350)**
Age [b]		1 (-)	-0.02523 (0.5280)	-0.44646 **(<0.0001)**
Cotinine [c]			1 (-)	-0.03462 (0.3864)
Income [d]				1 (-)

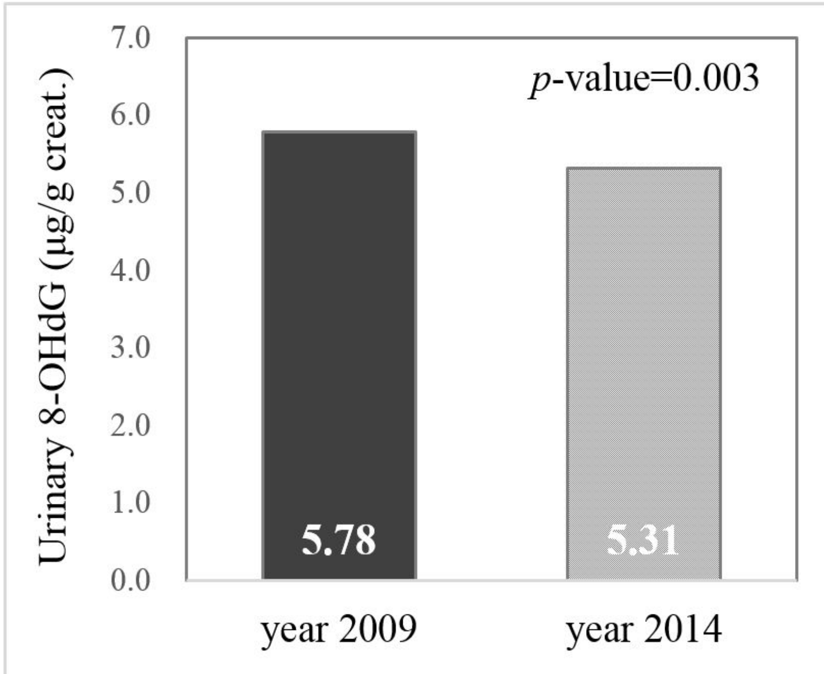
[a] Female and male.
[b] Continuous age.
[c] Creatinine corrected urinary cotinine level (Q1-Q4).
[d] Monthly household income (< 50, 50-199, ≥ 200).

Figure S1. Unadjusted geometric means of oxidative stress biomarkers in year 2009 and 2014.

A) MDA



B) 8-OHdG



* paired t-test

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국문 초록

허베이스피리트호 유류유출사고 6년 후 피해지역 주민의 산화손상지표 농도

김 정 아
서울대학교 보건대학원
환경보건학과 환경보건 전공

2007년 12월 7일, 서해안의 태안 앞바다에서 허베이스피리트호 유류유출사고가 발생했다. 사고 1.5년 후 지역주민의 체내 산화손상지표와 유류노출과의 양의 상관성이 보고되었다. 본 연구의 목적은 태안 인근 지역 주민을 대상으로 사고발생 6년 후 시점의 산화손상과 유류노출과 관계에 대해 조사하는 것이다.

연구 대상자는 유류유출 지점으로부터 거리를 구분하여 모집되었고, 설문지 작성 및 생체시료 수집 등에 참여하였다. 최종 연구대상자는 사고지점으로부터 20 km 이내 지역에 거주하는 476명의 성인과 20 km 초과 지역에 사는 152명의 성인으로 이루어져 있다. 연구대상자의 12시간 소변 중 DNA의 산화적 손상을 나타내는 8-hydroxy-2-deoxyguanosine (8-OHdG)와 지질과산화를 나타내는 Malondialdehyde (MDA) 농도를 측정하였다. 통계분석은 SAS 패키지의 GLM 절차를 사용한 다변량 선형모델 등을 통해 실시하였다.

전체 연구대상자의 소변 중 8-OHdG와 MDA 농도의 기하평균 및 기하표준편차는 각각 5.31 (1.78) μg/g creatinine 과 2.15 (1.71) μmol/g creatinine이었다. 8-OHdG와 MDA의 농도는 유류노출 정도(방제작업 참여일수, 사고지점으로부터 거주지까지의 거리)와

유의한 상관관계를 나타내었다. 성별 및 연령, 월수입, 요중 코티닌 농도는 혼란변수로서 보정을 위해 통계모델에 포함되었다.

분석 결과 피해지역 성인들에게서 유류유출사고가 발생한지 6년이 지난 시점에서도 거주지역 또는 방제작업 참여일수와 소변 중 산화손상지표 농도가 유의미한 양의 관계에 있음을 확인하였다. 본 연구결과는 유류오염으로 인한 건강영향이 수년간 지속됨을 시사한다. 이에 따라 지역주민에 대한 지속적인 건강영향조사 및 원인관계 규명을 위한 기전조사가 수행되어야 하며, 유사사고 발생시의 노출과 건강 악영향을 최소화하기 위한 관리방안과 대책이 개선되어야 한다.

주요어 : 환경재난, 유류노출, 장기적 건강영향, 유류유출, 산화손상, MDA, 8-OHdG

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