Health Survey on Workers and Residents Near the Municipal Waste and Industrial Waste Incinerators in Korea

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Abstract: Hazardous substances, such as polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) also have been detected in Municipal Solid Waste (MSW) and industrial waste incinerators in Korea. In this study, we estimated the exposure status of these hazardous substances and their health effects in workers and residents near the MSW incinerators and residents near the industrial waste incinerators. We interviewed 13 workers and 16 residents from the area around the two MSW incinerators, and further 10 residents from the area around one industrial waste incinerator, which is suspected to emit higher hazardous substances. During the interview we collected information including sociodemographic information, personal habits, work history, detailed gynecologic and other medical history. Blood samples from 45 subjects were also collected for analysis of PCDDs and PCDFs, which were analyzed by HRGC-HRMS (High Resolution Gas Chromatography - High Resolution Mass Spectrometer). In addition to a questionnaire survey, urinary concentrations of 8-hydroxydeoxyguanosine (8-OH-dG) and malondialdehyde (MDA) were measured as oxidative injury biomarkers. Urinary concentrations of 8-OH-dG were determined by in vitro ELISA (JAICA, Fukuroi, Japan). MDA were determined by HPLC using adduct with TBA (thiobarbituric acid). The PCDD/F concentrations in residents from the area around industrial waste incinerator were higher than those in workers and residents from the area around MSW incinerator. The average toxic equivalency (TEQ) concentrations of PCDD/Fs in residents from the area around industrial waste incinerator were 53.4 pg I-TEQs/g lipid. The average TEQ concentrations of PCDD/Fs in workers and residents near MSW incinerator were 12.2 pg I-TEQs/g lipid. Estimated daily intake (EDI) of each person was calculated, and the EDI of all workers and residents near MSW incinerator were within the tolerable daily intake range. But for only 30% of 10 people near the industrial waste incinerator were the EDI within the tolerable daily intake range (1–4 pg I-TEQ/kg bw/day) suggested by WHO (1997). The oxidative stress of residents near the industrial waste incinerator was higher than that in workers and residents from the area around MSW incinerator. This oxidative stress may have been caused by hazardous substances, such as PCDD/Fs emitted by incinerators. The residents from the area around industrial waste incinerator were exposed to hazardous substances such as PCDD/Fs. Proper protection strategies against these hazardous chemicals are needed.

Key words: Human blood, PCDDs, PCDFs, PCBs, HRGC/HRMS, Industrial waste incinerator, Oxidative stress

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Introduction

Many incinerators have been constructed since the early 1990s in Korea due to the lack of available land fill sites. In 1993, the incineration rate of municipal solid waste (MSW) in Korea was about 2.4%. It will be increased up to 30% by the year 2011\(^1\). But without proper technical strategies for emission reduction of dioxins and furans, this incineration-favored policy continue to face the dioxin-emission problem as the construction activities of further commercial-scale incineration facilities are increased. Since toxic substances, such as polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) have been detected in MSW and industrial waste incinerators in various countries, much public concern has been attached to the problem of environmental pollution and health effects by dioxin analogues. In 1996, the dioxin issues raise its head in relation to MSW incinerators through mass media. Local residents resist the construction and operation of MSW incinerators. In 1997, the control of PCDD/Fs emission from MSW incinerators was implemented in the Republic of Korea.

The emission concentrations of the MSW incinerators have been decreased below 0.005 ng-TEQ/Nm\(^3\) by dioxin-control policy, but those of industrial waste incinerators have remained high in Korea.

Dioxin is an unwanted by-product of incineration, uncontrolled burning and certain industrial processes. The term “dioxin” refers to a large family of compounds that includes 17 compounds of particular interest because it is thought that these compounds have similar mechanisms of toxicity. Nevertheless, the toxicities of dioxins vary greatly, with the least toxic compound estimated to be 10,000 less potent than the most toxic one. Dioxins occur as complex mixtures of these 17 family member compounds. The higher chlorinated PCDD/F like TCDD appear to be highly persistent in humans with half-lives ranging between 4 and 12 yr. PCDD/Fs persistent in environment, bioaccumulate through the food web, and pose a risk of causing adverse effects to human health and environment\(^2,3\).

There are many studies concerning the exposure, toxicity and health effects of PCDD/Fs\(^4-18\), but there are a few studies which investigated the exposure and health outcome assessment in workers and residents near incinerators in Korea\(^19-23\). In this study, we estimated the exposure status of these hazardous substances and their health effects on workers and residents near MSW incinerator and residents near an industrial waste incinerator.

Materials and Methods

We interviewed 13 workers and 16 residents from the area around two MSW incinerators at Seoul, and further 10 residents from the area around an industrial waste incinerator at Pyongtack where high emissions of dioxins are suspected. Study subjects were randomly selected among volunteers so that workers have been employed at incinerators and residents also have lived within 1.5 Km from MSW and industrial incinerators for more than 1 year. During the interview, we collected information including sociodemographic information, personal habits, work history, detailed gynecologic and other medical history. Blood 150 cc were also collected from 39 subjects for analysis of PCDDs and PCDFs from the residents near the incinerator and the workers at the incinerators. Serums were obtained from blood samples with centrifuge. Then serums were transferred to reliable laboratory with 4\(^\circ\)C ice box. PCDDs and PCDFs were analyzed by HRGC-HRMS (High Resolution Gas Chromatography -High Resolution Mass Spectrometer) according to US EPA 1613 method. Instrumental analysis was conducted by the School of Environmental Engineering at Pohang University who cooperated with our teams for quality assurance/quality control (QA/QC).

The body burden of PCDD/Fs are calculated from the following equations, because PCDD/Fs in blood lipids move into the tissues of other organ.

\[
\text{Body Burden (ng TEQ/kg bw)} = C_{\text{blood}} \times f_1
\]

\(C_{\text{blood}}\): concentration in blood
\(f_1\): percentage of body fat\(^31\)

For males:
\(f_1 = 1.264 \times \text{eight (kg)} / \text{height}^2 (\text{m}^2) – 13.305\)

For females:
\(f_1 = 1.030 \times \text{eight (kg)} / \text{height}^{1.5} (\text{m}^{1.5}) – 0.835\)

Estimated daily intake (EDI) of PCDD/Fs is calculated by following equation with body burden suggested by WHO, 1988\(^32\).

\[
\text{Under steady state condition, Intake (ng/kg bw/day)} = \text{Body Burden (ng/kg)} \times \ln(2)/\text{half-life}/f
\]

\(\text{an estimated half-life for TCDD: 7.5 years}\)
\(f\): the fraction of dose absorbed and is assumed to be 50% for absorption from food for humans

In addition to a questionnaire survey, urinary concentrations of 8-hydroxydeoxyguanosine (8-OH-dG) and malondialdehyde (MDA) were measured as oxidative injury...
biomarkers. Urinary concentrations of 8-OH-dG were determined by in vitro ELISA (JAICA, Fukuroi, Japan). MDA were determined by HPLC using adduct with TBA (thiobarbituric acid).

Statistical analysis was performed by Mann-Whitney U test, \( \chi^2 \) test, and GLM (generalized linear model) using SPSS 10.0 to test the differences of exposure status and health effects between the study subjects.

### Results and Discussion

#### Exposure assessment of PCDD/Fs homologue in workers and residents near Municipal Solid Waste (MSW) incinerators

Blood PCDD/Fs corrected by blood lipid are highly correlated with those of other human tissues. Blood PCDD/Fs also show high correlation with those of body and milk lipids. Blood specimens are generally used for human risk assessment\(^{24,25}\). The mean and SD (standard deviation) of 17 PCDD/F isomer concentrations in workers and residents near the MSW incinerators are presented as follows (Table 1). Seventeen PCDD/F isomer concentrations in workers and residents near the MSW incinerator are given as TEQ (toxic equivalencies) calculated by the internationally used I-TEFs (international-toxic equivalency factors) suggested by NATO in 1988\(^{26}\). There were no differences of PCDD/Fs isomer concentrations between workers at incinerators and residents near the MSW incinerators. With Mann-Whitney U test, there were no evidences of any differences between the two groups except OCDD. Relatively higher value of OCDD was unusual in residents near the MSW incinerators.

In 1997, WHO recommend 10–30 pg I-TEQ/g lipid as the background level of PCDD/Fs. In this study, the total TEQ concentrations of PCDD/Fs of workers and residents near the MSW incinerator were within the background levels. Estimated daily intake (EDI) of each person was calculated, and all of workers and residents near MSW incinerator were within the tolerable daily intake range. This means that MSW incinerators now do not affect the level of PCDD/Fs in workers at incinerators and residents near MSW incinerators.

#### Exposure assessment of PCDD/Fs homologue in residents near the industrial incinerator

Total TEQ concentrations of PCDD/F of residents near the industrial waste incinerator were higher than the background levels. The average TEQ concentrations of PCDD/Fs in residents near the industrial waste incinerator were 53.4 pg I-TEQs/g lipid, while those of PCDD/Fs in workers and residents near MSW incinerator were 11.4 pg I-TEQs/g lipid (Table 2). The average TEQ concentrations of PCDD/F isomers in residents near the industrial waste

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<table>
<thead>
<tr>
<th>PCDD/DF congeners</th>
<th>I-TEFs</th>
<th>Workers (n=13)</th>
<th>Residents (n=16)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td></td>
</tr>
<tr>
<td>2,3,7,8-TCDD</td>
<td>1</td>
<td>n.d.</td>
<td>n.d.</td>
<td>–</td>
</tr>
<tr>
<td>1,2,3,7,8-PeCDD</td>
<td>0.5</td>
<td>0.744 ± 1.09</td>
<td>1.678 ± 2.146</td>
<td>.325</td>
</tr>
<tr>
<td>1,2,3,4,7,8-HxCDD</td>
<td>0.1</td>
<td>0.119 ± 0.263</td>
<td>0.230 ± 0.290</td>
<td>.227</td>
</tr>
<tr>
<td>1,2,3,6,7,8-HxCDD</td>
<td>0.1</td>
<td>1.588 ± 1.164</td>
<td>2.724 ± 1.412</td>
<td>.059</td>
</tr>
<tr>
<td>1,2,3,7,8,9-HxCDD</td>
<td>0.1</td>
<td>0.301 ± 0.433</td>
<td>0.418 ± 0.480</td>
<td>.499</td>
</tr>
<tr>
<td>1,2,3,4,6,7,8-HpCDD</td>
<td>0.01</td>
<td>0.211 ± 0.251</td>
<td>0.316 ± 0.238</td>
<td>.073</td>
</tr>
<tr>
<td>OCDD</td>
<td>0.001</td>
<td>0.341 ± 0.475</td>
<td>0.915 ± 1.236</td>
<td>.030</td>
</tr>
<tr>
<td>2,3,7,8-TCDF</td>
<td>0.1</td>
<td>0.410 ± 0.914</td>
<td>0.015 ± 0.059</td>
<td>.370</td>
</tr>
<tr>
<td>1,2,3,7,8-PeCDF</td>
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<td>0.056 ± 0.144</td>
<td>n.d.</td>
<td>.471</td>
</tr>
<tr>
<td>2,3,4,7,8-PeCDF</td>
<td>0.5</td>
<td>4.812 ± 3.300</td>
<td>5.999 ± 3.392</td>
<td>.303</td>
</tr>
<tr>
<td>1,2,3,4,7,8-HxCDF</td>
<td>0.1</td>
<td>0.800 ± 0.641</td>
<td>0.589 ± 0.487</td>
<td>.499</td>
</tr>
<tr>
<td>1,2,3,6,7,8-HxCDF</td>
<td>0.1</td>
<td>0.476 ± 0.488</td>
<td>0.546 ± 0.468</td>
<td>.616</td>
</tr>
<tr>
<td>2,3,4,6,7,8-HxCDF</td>
<td>0.1</td>
<td>0.306 ± 0.681</td>
<td>0.169 ± 0.205</td>
<td>.616</td>
</tr>
<tr>
<td>1,2,3,7,8,9-HxCDF</td>
<td>0.1</td>
<td>n.d.</td>
<td>n.d.</td>
<td>–</td>
</tr>
<tr>
<td>1,2,3,4,6,7,8-HpCDF</td>
<td>0.01</td>
<td>0.214 ± 0.265</td>
<td>0.112 ± 0.049</td>
<td>.097</td>
</tr>
<tr>
<td>1,2,3,4,7,8,9-HpCDF</td>
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<td>0.004 ± 0.014</td>
<td>n.d.</td>
<td>.711</td>
</tr>
<tr>
<td>OCDF</td>
<td>0.001</td>
<td>0.003 ± 0.009</td>
<td>0.001 ± 0.004</td>
<td>.647</td>
</tr>
</tbody>
</table>

n.d.=non detected.
incinerator range from 2.4 (1,2,3,4,6,7,8-HpCDD) to 130.7 (1,2,3,4,7,8,9-HpCDF) higher than those of workers and residents near the MSW incinerators. As compared by Mann-Whitney U test, there were significant differences in the average TEQ concentrations of PCDD/F isomers between the two groups except 2,3,7,8-TCDD, OCDD and OCDF (P<.01). The ratio of total PCDD/Fs between the two groups was 4.7, and ratio of total PCDFs was higher than that of total PCDDs. The 17 PCDD/F isomers concentrations in the 10 residents near the industrial waste incinerator are presented in Table 3. The average TEQ concentrations of PCDD/Fs were 14.91 pg I-TEQ/g lipid, and those of PCDF isomers were 38.51 pg I-TEQ/g lipid in the 10 residents. The characteristic pattern of PCDD/F isomers is closely related with their sources of PCDD/Fs27–30) . Further study is needed to investigate relationships between the increased TEQ concentrations of PCDD/F isomers and particular sources.

EDI of each person was calculated, only 30% to the total people near industrial waste incinerator were within the tolerable daily intake range (1–4 pg I-TEQ/kg bw/day) suggested by WHO (1997).

Average TEQ concentrations of t-PCDD/Fs in the blood samples of general population in Europe are 14–43 pg I-TEQ/g lipid, 19–27 pg I-TEQ/g lipid in North America, 20–22 pg I-TEQ/g lipid in Japan35). Twelve PCB isomer concentrations are calculated as TEQ calculated by I-TEFs suggested by WHO in 199734) . According to Yoon-Hee Yang’s study in Korea19) , the average TEQ concentration of PCBs in workers is 7.32 pg I-TEQ/g lipid, and in residents 7.20 pg I-TEQ/g lipid. Because these levels were within the background concentrations compared to those of other countries35) , we did not consider the PCBs in this study.

In Korea, there were total 14,791 incinerators, out of which 97% were small-scale incinerators, whereas medium and large-scale incinerators were only 2.4% and 0.6%, respectively. Among total 14,791 incinerators, 69.4% are industrial waste incinerators (Table 4). The emission concentrations of the MSW incinerators have been decreased below 0.005 ng-TEQ/Nm3 by dioxin-control policy, but those of industrial waste incinerators have remained high in Korea. Our study shows that residents near the industrial waste incinerators have higher average TEQ of PCDD/Fs than those of other residents. According to report from Siwha industrial area in Korea, workers at some industrial waste incinerators also are exposed to PCDD/Fs above the background concentrations19) .

Table 2. Distribution of PCDD/DFs homologue in workers and residents near the MSW incinerators and residents near the industrial waste incinerator

<table>
<thead>
<tr>
<th>PCDD/DF congeners</th>
<th>Workers and residents near MSW incinerators (n=29)</th>
<th>Residents near industrial waste incinerator (n=10)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td></td>
</tr>
<tr>
<td>2,3,7,8-TCDD</td>
<td>1 n.d</td>
<td>n.d</td>
<td>-</td>
</tr>
<tr>
<td>1,2,3,7,8-PeCDD</td>
<td>0.5 1.260 ± 1.794</td>
<td>14.074 ± 11.709</td>
<td>.007</td>
</tr>
<tr>
<td>1,2,3,4,7,8-HxCDD</td>
<td>0.1 .180 ± .279</td>
<td>n.d</td>
<td>.000</td>
</tr>
<tr>
<td>1,2,3,6,7,8-HxCDD</td>
<td>0.1 2.215 ± 1.407</td>
<td>n.d</td>
<td>.000</td>
</tr>
<tr>
<td>1,2,3,7,8,9-HxCDD</td>
<td>0.1 .365 ± .456</td>
<td>n.d</td>
<td>.000</td>
</tr>
<tr>
<td>1,2,3,4,6,7,8-HpCDD</td>
<td>0.01 .269 ± .246</td>
<td>.587 ± .251</td>
<td>.000</td>
</tr>
<tr>
<td>OCDD</td>
<td>0.001 .658 ± 1.000</td>
<td>.252 ± .181</td>
<td>.145</td>
</tr>
<tr>
<td>2,3,7,8-TCDF</td>
<td>0.1 .192 ± .633</td>
<td>1.344 ± 1.029</td>
<td>.001</td>
</tr>
<tr>
<td>1,2,3,7,8-PeCDF</td>
<td>0.05 .025 ± .098</td>
<td>1.262 ± 1.106</td>
<td>.000</td>
</tr>
<tr>
<td>2,3,4,7,8-PeCDF</td>
<td>0.5 5.471 ± 3.345</td>
<td>18.239 ± 9.906</td>
<td>.000</td>
</tr>
<tr>
<td>1,2,3,4,7,8-HxCDF</td>
<td>0.1 .684 ± .562</td>
<td>4.349 ± 2.429</td>
<td>.000</td>
</tr>
<tr>
<td>1,2,3,6,7,8-HxCDF</td>
<td>0.1 .515 ± .470</td>
<td>4.033 ± 1.339</td>
<td>.000</td>
</tr>
<tr>
<td>2,3,4,6,7,8-HxCDF</td>
<td>0.1 .231 ± .476</td>
<td>3.947 ± 2.615</td>
<td>.000</td>
</tr>
<tr>
<td>1,2,3,7,8,9-HxCDF</td>
<td>0.1 n.d.</td>
<td>3.628 ± 2.127</td>
<td>.000</td>
</tr>
<tr>
<td>1,2,3,4,6,7,8-HpCDF</td>
<td>0.01 .158 ± .184</td>
<td>.740 ± .379</td>
<td>.000</td>
</tr>
<tr>
<td>1,2,3,4,7,8,9-HpCDF</td>
<td>0.01 .001 ± .009</td>
<td>.183 ± .1230</td>
<td>.000</td>
</tr>
<tr>
<td>OCDF</td>
<td>0.001 .002 ± .006</td>
<td>.025 ± .334</td>
<td>.043</td>
</tr>
<tr>
<td>t-PCDD/DFs</td>
<td>12.225 ± 7.787</td>
<td>53.420 ± 23.962</td>
<td>.000</td>
</tr>
</tbody>
</table>

n.d.=non detected.

Health assessment with biomarkers of oxidative damage
MDA and 8-OH-dG are available biomarkers to monitor
185 HEALTH SURVEY ON PEOPLE IN & OUT OF WASTE INCINERATORS

The mean concentrations of MDA in residents near the industrial waste incinerator were 268.5 mol/mol creatinine, and those of workers and residents near the MSW incinerators were 120.3 mol/mol creatinine. These differences between the two groups were statistically significant with Mann-Whitney U test (Table 5). There is no differences of BMI or sex ratio between residents near the industrial waste incinerator and workers and residents near the MSW incinerators. This oxidative stress have been caused by aging, smoking, diet habits and hazardous substances, such as PCDD/Fs emitted by incinerators. With analysis of covariance (ANCOVA), residency near the industrial waste incinerator is significant variable which is increasing MDA, after controlling smoking, aging, BMI, and diet habits (P<.01). This means that the oxidative stress of residents near the industrial waste incinerator was higher than that in workers and residents near the MSW incinerators. The mean concentrations of 8-OH-dG in residents near the industrial waste incinerator were 17.0 µg/g creatinine, and those of workers and residents near MSW incinerators were 15.6 µg/g creatinine. The association of MDA as biomarker of lipid peroxidation and PCDD/Fs were significant, because PCDD/Fs are lipid soluble. Oxidative damage may inhibit cell-mediated immunity toward infectious agents, exacerbate respiratory allergy, cause DNA damage, and under long-term exposure, induce the development of tumors.

**Conclusion**

Among total 14,791 incinerators in Korea, industrial waste incinerators and small and medium-scale incinerators command a majority. But they are not regulated well in...
Korea, the residents near the industrial waste incinerator were exposed to hazardous substances such as PCDD/Fs. Proper integrated management system against these hazardous chemicals are needed; continuous monitoring of dioxins in environmental media and humans, establishment of a national emission inventory of dioxins, risk assessment of dioxin, and control of emission sources.

### Reference


after exposure to 2,3,7,8-TCDD. Food Addit Contam 17, 303–16.
38) Hengstler JG, Bolm-Audorff U, Faldum A, Janssen K,


