Occupational Exposure Levels of Bisphenol A among Chinese Workers

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Abstract: Occupational Exposure Levels of Bisphenol A among Chinese Workers: Yonghua He, et al. School of Public Health/WHO Collaborating Center for Occupational Health, Fudan University, PR China—Objectives: The purpose of this study was to assess ambient Bisphenol A (BPA) levels in workplaces and urine BPA levels of workers. Methods: Workers in epoxy resin and BPA manufacturing factories were recruited. Personal samples for airborne BPA were taken in the workshops and spot urine samples were collected from workers before and after their shifts. The samples were assayed with high-performance liquid chromatography with a fluorescence detector. TWA8 of airborne PBA in the workplaces and biological BPA burden of the workers were calculated. Correlations between the external and the internal exposure levels were sought. Results: Workers from the factories were occupationally exposed to BPA at median personal airborne levels of 6.67 µg/m³ (or at the mean of 450 µg/m³). More than 90% of the workers who were occupationally exposed to BPA had detectable BPA levels in their blood samples. The medians of creatinine-adjusted urinary BPA levels were 84.6 µg/g Cr and 111 µg/g Cr pre- and post-shift (means of 4,630 µg/g Cr and 5,400 µg/g Cr), respectively. The urinary BPA concentration post-shift was significantly associated with the urinary BPA level pre-shift and personal airborne BPA levels. Conclusions: It was indicated that workers in epoxy resin and BPA manufacturing factories are occupationally exposed to BPA at high levels. There is an urgent need to create occupational standards and take effective preventive measures to protect workers from the potential adverse effects of BPA.

Key words: Bisphenol A, Exposure level, TWA, Urine, Worker

Bisphenol A (BPA) is a high-volume (>6 billion pounds per year) production chemical which is mainly used to make resin, polycarbonate plastic, polysulfones and polyurethanes. BPA has been demonstrated to be both estrogenic and anti-androgenic, leading to a decrease in sperm production in humans¹ and abnormal development of puberty in experimental animals ². It may also increase carcinogenic risk, prevalence of cardiovascular diseases and diabetes in humans³–⁶.

As the production and consumption of BPA is growing dramatically around the world, more and more workers are being occupationally exposed to BPA. Given the potential adverse affects of BPA on human health, it is necessary to assess the occupational exposure levels of workers and to establish exposure limits to protect workers. The present study investigated the occupational exposure levels of BPA in Chinese factory workers.

Materials and Methods

Subjects and sampling

This study was approved by the Institutional Review Boards of Fudan University, Shanghai Institute of Planned Parenthood Research, Shanghai, China, and the Kaiser Foundation Research Institute, Kaiser Permanente, Oakland, California. Study subjects were workers occupationally exposed to BPA in 4 factories in east and central China. The main product of the factories was epoxy resin. BPA was also produced on a small scale in 2 of the factories.

Subjects were randomly selected from the factories, but were required to have been working in their present
factory for more than 6 mo. Workers who had a dental sealant application in the last 1 yr were excluded. The participating subjects signed informed consent forms and were asked to provide urine specimens of 5 ml before and after their regular work shift on a workday.

During the field investigation, a total of 167 representative workers were asked to carry personal sampling pumps (MSA Escort ELF) on their lapels during the entire shift to take samples, with glass microfiber filter membranes (from Whatman International Ltd.) as the sorbent according to National Standard of Air Sampling in Workplaces of China (GBZ 159-2004). The sampling lasted for 3 days on the workers as required by the standard. The personal sampler with the glass fiber membrane was set at a flow rate of 2 l/min.

The day for collection of air samples was not always on the same as the day for the collection of urine samples from each of the workers, but the air sampling and urine sampling were completed within three working days. All samples were stored at ~70°C before high-performance liquid chromatography with a fluorescence detector (HPLC/FLD) analysis.

Analysis of BPA in the air and urine samples

The air sample filters were vortexed in 2 ml acetonitrile (HPLC grade, Dikma) to extract BPA, and then the solutions were centrifuged for immediate analysis with HPLC. The personal exposure level (TWA_p) was computed by the equation:

\[ TWA_p = \frac{(\text{Airborne Exposure Concentration} \times \text{Working Hours})}{8} \]

Total BPA (conjugated and free) in urine samples was measured based on the modified methods of Yang et al. Briefly, the reaction mixtures of phosphorous acid buffer, β-glucuronidase (Sigma) and sample aliquots in glass tubes were incubated for hydrolyzation, and were then extracted twice with ether (HPLC grade, Dikma). The supernatants were collected and evaporated with nitrogen gas. The residue was dissolved in 60% acetonitrile and analyzed by HPLC with the following parameters: column: Inertsil ODS-3, 4.6 mm × 250 mm, 5 µm; mobile phase: acetonitrile/water (40:60, v/v), equivalent grade; flow: 1.0 ml/min; FLD: excitation wavelength 275 nm, emission wavelength 300 nm. Water was from Millipore Super-Q Plus water purification system (Bedford, MA).

BPA was confirmed by use of standard BPA (HPLC grade, Shanghai Yuanxing Company) with the same HPLC equipment. The limit of detection (LOD) was calculated with methods recommended by U.S Environmental Protection Agency (EPA). The LODs of BPA in air and urine were 0.20 µg/m³ and 0.31 µg/l, respectively. Urinary BPA levels were adjusted for creatinine (Cr) content of the samples.

Statistical analysis

The raw materials and processes are completely different between resin manufacturing and BPA manufacturing, so the occupational exposure levels were separately assessed in the two workshops. As there were many workers in the epoxy resin manufacturing factories, not all of the workers in the epoxy resin factories carried personal sampling pumps. All of the participants in the BPA manufacturing workshop were asked to carry the personal sampling pumps, and the results were used as their personal exposure levels.

BPA concentrations in air or urine samples are presented as mean, median, and 25th–75th percentile. Values under the LOD were substituted with half of LOD in the computation of means. The Chi-square test was used to determine the statistical significance of differences of detection rates in the samples among the groups. We compared age and personal exposure levels of airborne BPA between participants and non-participants with a Mann-Whitney Nonparametric Test. Differences between urinary BPA levels pre- and post-shift were checked with a nonparametric test (Wilcoxon test for paired data). Workers with the same job title in the factory shared similar environmental exposure levels which were used as the mean of the personal exposure level of the job title in the factory when Spearman’s nonparametric correlations of urinary BPA levels pre-shift and post-shift, and airborne BPA concentrations were analyzed for workers who contributed both pre- and post-shift urine samples.

Quality control

Well trained field investigators and HPLC operators with professional experience in occupational hygiene and chemical analysis were involved in this project. Several pilot studies were performed before conducting the fieldwork. The containers for the biological samples were plastic tubes and were reported to be BPA-free by the supplier. A test was performed using HPLC analysis to check if there was any difference in the BPA level of the same urine sample stored in the plastic tube and in the glass tube at 4°C for 8 h. The results did not show any significant difference, indicating a low likelihood that the biological samples were being contaminated by BPA from the containers. Blank samples were randomly included during each HPLC analysis and no BPA was detected. A urine sample of defined concentration, 4.5 mg/l, was included in parallel analysis 5 times during every HPLC analysis round, and the concentrations were identified accurately.

Results

Characteristics of subjects

Semi-automatic manufacturing lines were used in the factories. The chemical processes were enclosed in reaction...
pots, but raw materials and products were manually handled by workers. Three shifts were performed in the factories. There were protective measures such as local exhaust ventilation at all worksites, but they were not always used by workers. Personal protective equipment including gloves and dust masks were provided and used sometimes. The restrooms were in the workshops, not far away from the process line. The cafeterias were located in factory blocks. Workers often took a bath and changed their clothes after their shift.

There were 177, 70, 56 and 22 workers engaged in epoxy resin manufacturing at the 4 factories, and 20 workers engaged in BPA manufacturing at 2 of the factories. About 66% (228) of subjects worked at reaction workstations, and 13% (43) of workers worked to crush and feed raw materials, and to pack the finished products; others were assistants such as technicians, supervisors and maintenance men. Table 1 shows the characteristics of the subjects. About 70% of the subjects were male. The mean age of the participants was 33.1 yr old, and there was no difference between the eligible workers and the participants by age. Of those eligible, 186 (54%) and 198 (57%) workers gave urine samples before or after their shift, respectively. Among participants, 131 contributed urine samples pre- and post-shift.

Airborne BPA concentrations in the factories

We calculated 161 TWA₈ from measurements of airborne BPA concentrations in the workplaces. BPA was detected in 96% of the air samples (Table 2), and the median of the concentration was 6.67 µg/m³. The rate of concentration >LOD was not different in resin workshops from that in BPA workshops (χ² = 0.155, p = 0.526), neither was the median of the airborne BPA concentration (z = -0.716, p = 0.474).

Urinary BPA concentrations of workers

In the pre-shift urine samples, the detection rate was significantly higher for the resin workers than for the BPA workers (94% vs 63%, Pearson χ² = 6.759, p = 0.009); while the rates for post-shift were higher than 90% for workers in both the workshops (Table 3). The median levels were 84.6 µg/g Cr and 111 µg/g Cr (means were 4,630 µg/g Cr and 5,400 µg/g Cr), respectively. The post-shift level was significantly higher than the pre-shift level (z = -7.299, p = 0.000). The concentrations in the urine samples were not significantly different between the resin workers and the BPA workers, pre- or post-shift.

Table 1. Characteristics of the eligible and the participant subjects

<table>
<thead>
<tr>
<th>Product</th>
<th>Eligible</th>
<th>Participant</th>
<th>Eligible</th>
<th>Participant</th>
<th>Eligible</th>
<th>Participant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Pre-shift</td>
<td>Post-shift</td>
<td>N</td>
<td>Pre-shift</td>
<td>Post-shift</td>
</tr>
<tr>
<td>Resin</td>
<td>325</td>
<td>178</td>
<td>191</td>
<td>208 (117)</td>
<td>120 (58)</td>
<td>137 (54)</td>
</tr>
<tr>
<td>BPA</td>
<td>20</td>
<td>8</td>
<td>7</td>
<td>16 (4)</td>
<td>6 (2)</td>
<td>5 (2)</td>
</tr>
<tr>
<td>Total</td>
<td>345</td>
<td>186</td>
<td>198</td>
<td>224 (121)</td>
<td>126 (60)</td>
<td>142 (56)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pre-shift</td>
<td>Post-shift</td>
<td>N</td>
<td>Pre-shift</td>
<td>Post-shift</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Male (Female)</td>
<td>Age (Yr old, Mean)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resin</td>
<td></td>
<td>208 (117)</td>
<td>120 (58)</td>
<td>137 (54)</td>
<td>33.1</td>
<td>33.3</td>
</tr>
<tr>
<td>BPA</td>
<td></td>
<td>16 (4)</td>
<td>6 (2)</td>
<td>5 (2)</td>
<td>31.1</td>
<td>31.2</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>224 (121)</td>
<td>126 (60)</td>
<td>142 (56)</td>
<td>33.1</td>
<td>33.3</td>
</tr>
</tbody>
</table>

Table 2. TWA₈ concentrations of airborne BPA in factories (µg/m³)

<table>
<thead>
<tr>
<th>Product</th>
<th>N</th>
<th>% (&gt;LOD)</th>
<th>Mean</th>
<th>Median</th>
<th>25th–75th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resin</td>
<td>145</td>
<td>96</td>
<td>492</td>
<td>7.89</td>
<td>1.55–55.2</td>
</tr>
<tr>
<td>BPA</td>
<td>16</td>
<td>93</td>
<td>51</td>
<td>4.72</td>
<td>2.09–6.06</td>
</tr>
<tr>
<td>Total</td>
<td>161</td>
<td>96</td>
<td>450</td>
<td>6.67</td>
<td>1.61–37.8</td>
</tr>
</tbody>
</table>

Table 3. Urinary BPA concentration of workers occupationally exposed to BPA (µg/g Cr)

<table>
<thead>
<tr>
<th>Pre-/post-shift</th>
<th>Product</th>
<th>N</th>
<th>% (&gt;LOD)</th>
<th>Mean</th>
<th>Median</th>
<th>25th–75th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-shift</td>
<td>Resins</td>
<td>178</td>
<td>94</td>
<td>4820</td>
<td>80.2</td>
<td>19.5–618</td>
</tr>
<tr>
<td></td>
<td>BPA</td>
<td>8</td>
<td>63</td>
<td>440</td>
<td>170</td>
<td>21.0–826</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>186</td>
<td>93</td>
<td>4630</td>
<td>84.6</td>
<td>19.5–618</td>
</tr>
<tr>
<td>Post-shift</td>
<td>Resins</td>
<td>191</td>
<td>94</td>
<td>5580</td>
<td>108</td>
<td>28.0–870</td>
</tr>
<tr>
<td></td>
<td>BPA</td>
<td>7</td>
<td>100</td>
<td>543</td>
<td>233</td>
<td>1.42–232</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>198</td>
<td>94</td>
<td>5400</td>
<td>111</td>
<td>26.6–934</td>
</tr>
</tbody>
</table>
in industries which do use it as a raw material. Results suggest that much lower airborne BPA levels are found in industries not using BPA as a raw material than those in industries which do use it as a raw material. The limitations affected the representativeness of the results to a certain extent. In summary, we found in the present study that workers from the potential adverse effects of BPA.

Correlation of the external and internal exposure levels of BPA

For the 131 workers who provided samples both before and after their shift, the median concentrations pre- and post-shift were 64 µg/g Cr and 131 µg/g Cr (means were 4,770 µg/g Cr and 923 µg/g Cr), respectively. The concentrations in the urine of workers who contributed samples both pre- and post-shift and workers who contributed samples pre- or post-shift urine sample(s) were not statistically different \( (z=-0.063, \ p=0.950 \) for pre-shift and \( z=-1.912 \ p=0.056 \) for post-shift). Correlation analysis of the 131 workers who contributed urine samples both pre- and post-shift showed that there was a significant correlation between levels of personal airborne BPA and urinary BPA pre-shift \( (\rho=0.753, \ p=0.000) \), as well as urinary BPA pre- and post-shift \( (\rho=0.726, \ p=0.000) \). The correlation of the external and internal exposure levels of BPA was significant. The occupational exposure levels of BPA. Also, the small sample size at the BPA manufacturing factories prevented us from fully exploring the BPA levels in these factories. The limitations affected the representativeness of the results to a certain extent.

Discussion

In this study, we found that workers were occupationally exposed to BPA at median personal airborne levels of 6.67 µg/m³ (or at mean of 450 µg/m³) at the factories. More than 90% workers who were occupationally exposed to BPA were found to have urinary BPA levels above LOD. The median urinary BPA concentration in people without occupational exposure was 2.5 µg/g Cr, much less than our occupationally exposed workers (84.6 µg/g Cr and 111 µg/g Cr pre- and post-shift, respectively). The correlation of the external and internal exposure levels of BPA was significant. The occupational exposure levels of BPA.

Based on the present study, we found the pollution sources were mainly the crushing, feeding and packing workstations. It would be effective to control worksite BPA exposure levels by health engineering such as enclosures, negative-pressure feeding material and local ventilation. Meanwhile, the development of TLVs and health training for workers are necessary to protect workers from the potential adverse effects of BPA.

There were some limitations to the study: the low participation rate and the heterogeneity of the participants and the nonparticipants limited the extrapolation of occupational exposure levels of BPA. Also, the small sample size at the BPA manufacturing factories prevented us from fully exploring the BPA levels in these factories. The limitations affected the representativeness of the results to a certain extent.

In summary, we found in the present study that workers in epoxy resin and BPA manufacturing factories were occupationally exposed to BPA at high levels. Given the potential adverse effects of BPA on human health, there is an urgent need to create occupational standards and develop effective measures to protect workers.

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References


