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# HEALTH, SOCIAL, AND ECONOMIC ISSUES OF ELECTRONIC WASTE RECYCLING WORKERS

<u>A. Schecter</u><sup>1</sup>, J. Kincaid<sup>2</sup>, H.T. Quynh<sup>3</sup>, H. Clair<sup>1</sup>, M. Cave<sup>1</sup>, M. Gagnier<sup>1</sup>, M. Ahmed<sup>1</sup>, R. Crandall<sup>1</sup>, K. Jawad<sup>1</sup>, S. Rashid<sup>1</sup>, L. Birnbaum<sup>4</sup>

<sup>1</sup>University of Louisville, Louisville, Kentucky, USA

<sup>2</sup>University of Southern California, Los Angeles, California, USA

<sup>3</sup>Centre for Ecologically Sustainable Agriculture, Hanoi, Vietnam

<sup>4</sup>National Center Institute, NIH, Research Triangle Park, North Carolina, USA

#### Introduction

Generation of electronic waste (e-waste) and electrical waste has risen exponentially with increasing demand for electronics worldwide. Consequently, there has been an emergence of industries centered on the recycling of e-waste for recovery of reusable materials. Of concern, 50 to 80 percent of e-waste generated by industrialized countries is exported to developing countries where laws governing e-waste recycling are often loosely enforced, especially for home-based recycling.<sup>1</sup> The health burden of e-waste recycling on developing countries is exacerbated by illicit exportation and improper "donation" of electronic equipment from the developed world to developing countries.<sup>2</sup>

E-waste recycling has become a lucrative industry. In 2016 it is expected to generate nearly \$20 billion globally.<sup>3</sup> E-waste disposal tends to be more profitable when it is exported to countries with relatively low wages and relaxed regulations.<sup>4</sup> As a result, developed countries are incentivized to export their e-waste to poorer countries. Furthermore, the high labor costs and strict environmental regulations associated with e-waste disposal in developed countries discourage these countries from processing their own e-waste and encourage them to ship it elsewhere.<sup>5</sup>

In developing countries, e-waste recycling offers employment to less skilled individuals. Individuals participating in e-waste recycling tend to come from low socioeconomic backgrounds.<sup>6</sup> Many of these people are drawn to e-waste recycling because it enables them to earn more money than they would performing other low wage jobs, such as rice farming. In Vietnam, rice farming is a primary source of income for many people. Rice farming, however, is both low paying and physically demanding (**Figure 1**). In some countries the financial earnings of e-waste recyclers are two-and-one half times greater than the average daily wage.<sup>7</sup> Although importing e-waste for recycling may generate some revenue, many developing countries lack the facilities and resources necessary to safely recycle and dispose of e-waste.<sup>5</sup> Consequently, some individuals set up home-based recycling operations, which may lead to hazardous working environments and toxic chemical exposure (**Figure 2**).

The aim of this paper is to shed light on social and economic issues pertaining to e-waste recycling by discussing the exposure of e-waste recyclers to toxins found in e-waste through media including water, air, soil, dust, and food. Some of these toxins have been associated with hazardous outcomes, such as increased DNA damage and adverse birth effects.<sup>1</sup> In Vietnam, a large amount of e-waste recycling occurs as a cottage industry. Much of the exposure to toxins occurs outside of a regulatory framework. This lack of regulation may not only endanger the increasing female recycler population but also the family members of these women, including husbands and children. Exposure to women is of special concern due to the woman's potential to pass toxic organics and metals to the infant prior to and after birth by nursing. Prenatal exposure to e-waste recycling may contribute to low birth weight, low Apgar scores, and unsafe levels of lead in the umbilical cord blood. Metal exposure in utero has been associated with lower birth weight, diminished lung function, higher incidences of ADHD, and chromosome damage.<sup>1</sup> Because liver and heart are among target organs for metals and organics exposures, clinical laboratory markers associated with liver and heart damage were analyzed. PBDEs, arsenic, cadmium, and lead are metabolic disrupters associated with liver and cardiac injury as well as nervous and cardiovascular system damage.<sup>1</sup> For this phase of the study, serum liver and cardiac biomarkers of inflammation, fibrosis, and metabolic dysfunction were measured.

Previously, a pilot study comparing Vietnamese female e-waste workers (n=10) with at least five years of e-waste recycling work to comparison subjects (n=10) from rural northern Vietnam with no known occupational exposure to e-waste was conducted. In that study, the e-waste workers were found to have increased levels of some serum persistent polybrominated diphenyl ethers (PBDEs), select metals

(urine and serum arsenic species, urine cobalt, urine total mercury, serum copper, serum zinc), and some serum polychlorinated biphenyls (PCB)s and biologically measured total dioxin and dioxin like toxicity.<sup>9</sup> In order to better characterize these findings in e-waste workers and to identify any exposure-related health and disease biomarkers in the worker population, a second group of e-waste workers (n=40) and comparison (n=20) subjects were recruited and selected findings are reported here and in our other abstract at this meeting.<sup>8</sup>

In both instances, blood and urine were analyzed at the Centers for Disease Control and Prevention (CDC), the same laboratory that analyzes the US general population in the National Health and Nutrition Examination Survey (NHANES) program. To date, twelve PBDEs, 37 PCBs, PBB-153, select pesticides and 30 metals/metal species were measured in urine, serum, and whole blood using the usual CDC methodology. Recyclers had elevated PBDE-47, PBDE-99, PBDE-100, PBDE-153, PBDE-154, PBDE-183, and PBDE-209 levels compared to non-recyclers. No statistically significant differences in PCB congener levels were usually found between workers and comparisons, except as noted in our other paper at this conference.<sup>8</sup> Of particular note are the metal exposures. Recyclers showed significantly higher levels of blood and urine lead than non-recyclers. Non-recyclers had significantly higher levels of blood and urine cadmium, blood and urine lead, blood and urine mercury, and also urine arsenic and arsenic species.<sup>8</sup>

### Materials and Methods

For a more detailed description of the study's methods, please reference this group's other presentation at Dioxin 2016.<sup>8</sup> Self-described non-smoking female e-waste industry workers (n=40) were recruited along with a group of age- and gender-matched female subjects without known exposures to e-waste (n=20).<sup>8</sup> Specimens from the women were analyzed first at the CDC laboratories of Andreas Sjödin (organics) and Kathleen Caldwell (metals) and then measured in the University of Louisville laboratories of Matt Cave and Aruni Bhatnagar for biomarkers of liver and cardiac damage.

The following markers of liver and cardiac inflammation, injury, and damage were measured: Cytokeratin 18-M30 (fibrosis indicator), cytokeratin 18-M65 (fibrosis indicator), interleukin-6 (fibrosis indicator), insulin (metabolic biomarker), leptin (metabolic biomarker), interleukin-8 (inflammatory marker), monocyte chemotactic protein-1 (MCP-1, inflammatory marker), tumor necrosis factor alpha (TNFα, inflammatory marker), interleukin-1B (inflammatory marker), adiponectin (metabolic biomarker), Resistin (metabolic biomarker), plasminogen activator inhibitor (PAI)-1 (fibrosis indicator), cholesterol, glucose, triglyceride, albumin, total protein, high density lipoprotein (HDL), low density lipoprotein (LDL), alanine aminotransferase (ALT, liver enzyme), aspartate aminotransferase (AST, liver enzyme), creatine kinase (CK), lactate dehydrogenase (LDH), creatinine, fibrinogen, and c-reactive protein (CRP). Cytokeratin-18 levels (whole and caspase-cleaved) were determined by ELISA (diaPharma). Cytokine and adipokines were determined by using Milliplex kits and analyzed on a Millipore Milliplex Analyzer (Billerica, MA). Additional cardiac and liver labs of clinical importance were determined using the Cobas Mira bench top random access biochemistry analyzer. Group means were compared by t-test. Finally, we determined levels of insulin resistance using the homeostatic model assessment of insulin resistance (HOMA-IR) standard clinical calculation. HOMA-IR is a clinical tool that is used as an insulin resistance index in clinical and epidemiological studies of non-alcoholic fatty liver disease.

#### Results

Compared to published reference ranges and laboratory cutoff values, mean fasting insulin was elevated in e-waste workers and not elevated in controls (233.8±189.7 and 147.0±93.6 pmol/L, respectively, compared to <174 pmol/L normal cutoff). Mean HOMA-IR was elevated in e-waste workers and controls ( $12 \pm 1.825$  vs. 7.143  $\pm 1.196$ , respectively – a score >2 is used to diagnose insulin resistance) and HOMA-B was likewise elevated in both groups ( $357.3\% \pm 75.87$  vs. 200.3%  $\pm 28.42$ ). While adiponectin was decreased in both groups ( $17.9\pm9.2$  and  $19.0\pm7.0$  ng/mL, compared to 22 ng/mL normal level for females) (Figure 3), the hepatocellular apoptosis biomarker CK18 antigen M30 was not elevated in either group. No significant differences in CK18-M65 were detected between groups, but the mean CK18-M65 was elevated for both groups, with levels above the normal cutoff of 300 U/L in 75% of ewaste recyclers and 90% of controls (Figure 4). Pro-inflammatory cytokines were not elevated in either group. No significant differences were noted between groups with respect to CK18 levels, inflammatory cytokines, fibrosis indicators or metabolic biomarkers. Although the individuals reported being in good health, the liver injury biomarker CK18-M65 was abnormally elevated in 78% of the entire population. Of those individuals, 69% displayed a CK-18 pattern consistent with predominantly necrotic (as opposed to apoptotic) hepatocyte death. In the entire population, insulin levels were unexpectedly high and adiponectin levels were unexpectedly low (the study population in general have low BMI's, therefore we would expect high adiponectin levels). Also, as evidenced by (Figure 5), both e-waste recyclers and non-recyclers showed PAI-1 levels that are elevated above the 2-15 AU/mL range. The only clinical marker to show a significant difference between recyclers and comparisons was triglycerides, which were higher in the recyclers (p<0.0015). It should be noted that many of the cardiac and liver markers were elevated in both groups and analysis is ongoing, especially with regard to determining insulin resistances and odds ratio.

#### Conclusion

Please refer to the author's other Dioxin2016 abstract to view the increased level of metals exposure to the Vietnamese subjects vs NHANES. <sup>8</sup> Abnormal biomarkers of subclinical liver damage as well as increased incidence of insulin-resistant diabetes (unbeknownst to the volunteers) in both groups indicate a potential public health problem that may be related to increased metals exposure. Of significance, the Vietnamese women compared to age matched US women from NHANES were found to have increased levels of the following metals: Whole blood cadmium, blood methyl mercury, blood manganese, blood lead, blood total mercury, urine arsenous (III) acid, urine arsenobetaine, urine cadmium, urine cobalt, urine total arsenic acid, urine thallium, and urine tungsten.<sup>8</sup>

Although the analysis using mechanistic biomarkers suggested subclinical liver injury in 78% of the overall Vietnamese population studied, there was no significant difference in standard clinical liver injury by the usual serum clinical tests for liver damage (e.g, AST and ALT, or other biomarkers) between the e-waste recycler and comparison populations. Finally, the elevated levels of PAI-1 (fibrosis biomarker) found in both groups' further may support the interpretation of an increased risk for at least subclinical liver damage in this population if exposures are not addressed (Figure 5). Because the indicated liver injury displays a pattern of hepatocellular necrosis typical of toxicant-associated steatohepatitis (fatty liver disease) instead of the predominantly apoptotic mechanism characteristic of non-alcoholic (obesity-associated) steatohepatitis, it is possible that the liver injury in this population is related to environmental exposures common in the region, such as arsenic, rather than exposures unique to e-waste workers.

Considering that the study population is composed of non-obese female subjects, the elevated insulin and low adiponectin levels were also unexpected. Typically adiponectin and BMI are inversely related. Lower BMIs usually mean higher adiponectin levels and are protective against cardiac and liver damage. Both e-waste recyclers and matched Vietnamese controls had serologic biomarkers compatible with insulin resistance and liver injury consistent with known exposures to metabolic disrupters. While no differences were seen between groups, recyclers and non-recyclers, these heightened levels could have been due to elevated arsenic and lead exposures, compared to NHANES values, present in both groups. Chronic hepatitis B infection, prevalent in South East Asia, including Vietnam, is another potential confounder to be evaluated. Again, ALT and AST levels, the usual markers for liver damage in clinical medicine, were not elevated. More research is needed to investigate possible insulin resistance and liver injury in e-waste workers as well as in arsenic- and lead-exposed populations in general. Analyses of the elevated liver and cardiac biomarkers are currently underway. Findings and comparisons of these liver and cardiac biomarkers to the NHANES general population is important for directing further research. Improved questionnaires and follow up visits are indicated for the Vietnamese groups. In addition, there is a need to study levels of the toxic chemicals in children as well as mothers from perinatal exposures. It was also noted that many women had their children with them while recycling e-waste. Exposure to various organics and metals can lead to long term neuro-developmental disorders in exposed individuals, especially children.<sup>1</sup> Finally, as reported in the authors' other Dioxin 2016 presentation, selenium levels were found to be statistically significantly lower in both the recyclers and comparisons than NHANES, how this difference is not clinically significant.

Even in formal recycling centers, as little as 25% of e-waste is estimated to be recycled with adequate worker protection.<sup>2</sup> Efforts should be made on global, national, and local scales to create safe electronic and electrical waste recycling environments, while at the same time allowing people who do this recycling and processing of electronic waste to continue to financially support themselves and their families. Economically feasible occupational measures including use of adequate personal protective equipment should be implemented as well as measures of environmental remediation. Not only is it important to develop safe environments and to support the financial needs of these electronic waste recyclers, it is imperative that exposure to toxic chemicals is notably decreased in all recyclers, especially the most at risk and vulnerable populations, including women and children.<sup>1</sup> A major challenge

is to support e-waste recycling as a legitimate and economically profitable undertaking so that the governments in countries where recycling is taking place are incentivized to build the infrastructure to maintain industry profitability, while simultaneously protecting human health and the surrounding environments.<sup>1</sup>

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#### Figure 1: Asian Rice Field Workers

This picture represents the typical working environment of rice paddy laborers. The individuals in this picture are from Cambodia, a country adjacent to Vietnam. Retrieved from: https://commons. wikimedia.org/ wiki/File: Cambodian\_farmers\_planting\_rice.jpg. Attribution: Brad Collis.



# Figure 2: Vietnamese Man and Woman Reclaiming Metals from Electronic Waste

E-waste recyclers collecting metals for resale; Dermal and respiratory exposure probable, including PXDD/Fs. The Vietnamese man and woman in this picture have consented to their pictures being used for research. X = Br, Cl or BR Cl.



Figure 3: Adiponectin levels were not significantly different between groups, however, Adiponectin was lower in both groups than would be expected in non-obese females.



Figure 4: CK18 M65 levels were not significantly different between groups. However, in both groups, mean CK18 M65 were above the normal cutoff of 300 U/L.



Figure 5: PAI-1 levels were not statistically different between recyclers and comparisons, however they were elevated.