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Genomic instability in adult men involved in processing electronic waste in Northern China

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ABSTRACT

Background: Managing and recycling electronic waste (e-waste), while useful and necessary, has resulted in significant contamination of several environments in China. The area around Tianjin, China has become one of the world's largest e-waste disposal centers, where electronics are processed by manually disassembly or burning, which can result in serious exposure of workers to a multitude of toxicants.

Objective: The present study assessed potential genomic damage in workers involved in recycling e-waste.

Methods: To detect cytogenetic and DNA damage, chromosomal aberrations (CA), cytokinesis blocking micronucleus (CBMN) and the comet assay were performed. Concentrations of some trace elements, markers of oxidative stress and polychlorinated biphenyls (PCBs) in whole blood or serum were measured, and relationships among the markers described above, age, and duration of exposure were analyzed. The profiles of expression of genes in lymphocytes in peripheral blood were assessed to determine the status of the regulation of genes involved in genome stability.

Results: Concentrations of 28 PCB congeners in the whole blood of the exposed group were significantly ($P < 0.001$) greater than those in the control individuals. Frequency of CA (8.01%) and CBMN (26.3‰) in lymphocytes and the level of DNA damage in the lymphocytes and spermatozoa of the exposed men were also significantly ($P < 0.0001$) greater than those of the controls. There were significant relationships between CA, CBMN, DNA damage and duration of exposure. Concentrations of malondialdehyde (MDA) and lead (Pb) in the blood serum were significantly greater, but activities of superoxide dismutase (SOD), glutathione (GSH) and concentrations of calcium (Ca) and magnesium (Mg) were lower in the serum of the exposed men. MDA, Pb, Ca and Mg were associated with the duration of exposure to handling e-waste. In males involved in handling of e-waste, there were 13 genes — ATM, ATR, ABL1, CHEK1, CHEK2, GADD45A, CDK7, GTSE1, OGG1, DDB1, PRKDC, XRCC1 and CCNH — for which expression of mRNA was up-regulated and 7 genes — BRCA1, GTF2H1, SEMA4A, MRE11A, MUTYH, PNKP and RAD50 — for which the expression of mRNA was down-regulated.

Conclusions: A strong correlation between indicators of damage of DNA, which could result in instability of the

Abbreviations: CA, chromosome aberrations; CBMN, cytokinesis-block micronucleus; CRTs, cathode-ray tubes; GAPDH, glyceraldehyde-3-phosphate dehydrogenase; GC–MS, gas chromatographic–mass spectrometry; GO, gene ontology; GSH, glutathione; HE, hematoxylin-eosin; MDA, malondialdehyde; OTM, olive tail moment; PBDEs, polybrominated diphenyl ethers; PCB, polychlorinated biphenyls; POPs, persistent organic pollutants; SOD, superoxide dismutase; SPE, Solid-phase extraction; TDNA%, the percentage of DNA in the comet tail; TM, tail moment

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genome, and duration of processing e-waste was observed. If proper procedures are not followed, there are significant risks to the health of the individuals involved in such activities.

1. Introduction

The global use of electronic equipment has increased dramatically over the last few decades, especially during the first decade of the 21st century. Electronics such as cell phones and computers are now used in all facets of life and provide significant benefits to society. According to Moore's Law, the microprocessor transistor count has doubled every one to two years since the early 1970s. This has resulted in electronics, especially personal devices, becoming obsolete at an exceedingly rapid pace. As a result, the production of e-waste has been increasing at approximately 4% per year (MH Wong et al. 2007) and has become the fastest growing waste stream in the industrialized world with approximately 20 to 50 million tons of e-waste being generated worldwide every year (Kumar and Singh, 2014; Lorenzen, 2014; Pramila et al., 2012). Some of the constituents in electronics are rare or valuable and thus are extracted for re-use. However, managing and recycling e-waste has become a major global challenge and environmental problem (Liu et al., 2009a; Tetteh and Lengel, 2017). In more economically developed countries, concerns about the potential effects of e-waste on human health and the environment have resulted in the export of e-waste to less developed countries, which may have less restrictive regulations. In fact, approximately 50 to 80% of e-waste produced globally is exported to Asia and Africa (Breivik et al., 2014; Daum et al., 2017; Ruan and Xu, 2016). Thus, the handling of e-waste is a global issue and has become one of social justice as well as being an economic issue.

Recently, an area near Tianjin, Northern China has become one of the largest centers for the recycling of electronic waste in China (Liu et al., 2009a). Due to a lack of policies to manage and control the recycling of e-waste in developing countries, much of this waste is processed in small-scale, unregulated family workshops where laborers manually disassemble electronics (Li et al., 2008; Liu et al., 2009b). The components of this waste, including electronic circuit boards or microchips, are then illegally burned so that valuable constituents can be extracted and reclaimed (see Fig. 1 in Ref [Du et al., 2018]). These procedures result in the release of a variety of chemicals to the environment. These contaminants are released primarily directly to the air but are also released directly and indirectly to the soil and water (Chatterjee, 2008; Leung et al., 2011). Among others, contaminants of concern released during the recycling of e-waste are metals such as lead (Pb), persistent organic pollutants (POPs) such as polychlorinated biphenyls (PCBs), and dioxin-like compounds, resulting in a variety of health risks (Chatterjee, 2007; Dallaire et al., 2014; Leung et al., 2011; CS Wong et al. 2007; Wu et al., 2009; Zhang et al., 2010). During these processes, organic and inorganic flame retardants, including those that are brominated such as polybrominated diphenyl ethers (PBDEs) or newer replacements are also released. For example, concentrations of Pb in the blood of children in e-waste recycling areas in China were significantly greater than those in the blood of children from non-e-waste recycling areas (Zheng et al., 2008). In fact, the exposure is approaching levels known to adversely affect the cognition and synthesis of heme in blood cells (Chen et al., 2011; Huo et al., 2007; Lu et al., 2017; Reglero et al., 2009b). Furthermore, a recent study by our groups has shown that local residents in the e-waste recycling industry of the Tianjin region exhibited oxidative stress-related health effects due to exposure to pollutants released during recycling (Li et al., 2013).

Despite concerns regarding potentially adverse effects on health due to participation in family-operated workshops, where the recycling of e-waste is often conducted in China and other countries in Asia and Africa, little is known about the specific effects on humans and their association with contaminants released during these practices. Most of the pollutants can damage DNA, which then can result in instability of the genome of workers or residents in the area where e-waste is recycled. The mechanisms of all of these effects are still unclear, but genetic toxicity from pollutants released during the processing of e-waste might be due to oxidative damage to nucleobases, induction of membrane lipid peroxidation, DNA methylation, and dysfunction of DNA repair, all of which can lead to human genetic instability (Singh et al., 2007). In an earlier study, it was demonstrated that people living in the e-waste recycling region of Tianjin exhibited cytogenetic damage of lymphocytes (Liu et al., 2009a). The aim of this study was to expand on previous investigations by conducting a comprehensive analysis of the potential health risks to humans working in e-waste disposal and recycling. Specifically, the quantity and quality of semen, profiles of gene expression, and cytogenetic effects, including chromosome aberrations, micronuclei in lymphocytes and DNA damage in both lymphocytes and spermatocytes were investigated.

2. Methods

2.1. Study population and sampling

The "exposed" group consisted of 146 male residents who were directly engaged in recycling e-waste but had no history of occupational exposure to other chemicals. All subjects from the exposed group were involved in dismantling e-waste on a daily basis, including melting and burning, during which vapors may have been inhaled. They all processed e-waste in similar family-workshops. The e-waste that they recycled mainly included discarded computers, TV sets and cathode-ray tube (CRTs) monitors. The reference group consisted of 121 men from a neighboring area located fifty kilometers from the exposure area, in which there was no recycling of e-waste or other chemical, industrial and agricultural pollution in the proximate vicinity (Liu et al., 2009a). The people in the reference group were all farmers who had planted vegetables, fruits and crops for many years. The demographic characteristics were determined via questionnaires administered to the subjects in the two groups (Table 1). In a previous study, it had been demonstrated that no significant cytogenetic damage occurred in subjects from this reference area (chromosome aberration: 1.70%) (Liu et al., 2009a) compared to the normal range (chromosome aberration: 1.61–3.30%) for Chinese people (Bai et al., 1993).

Peripheral blood and semen were collected from the two groups. To reduce variability among the results, only semen from men who had abstained from sexual activity between 2 and 7 days prior to collection were included in this study. All participants were instructed concerning the collection of semen by masturbation in a private and relaxed setting at Tianjin Medical University. Within 40 min of collection, analyses of the sperm were conducted in the genetics laboratory of Tianjin Medical University. In addition, a sample (10 ml) of venous blood was collected from each man, and concentrations of PCBs; trace elements, including Pb, copper (Cu), zinc (Zn), Ca, Mg, iron (Fe) and selenium (Se); chromosome aberrations (CA); cytokinesis-block micronucleus (CBMN); gene expression profiles; and DNA damage were measured. The Peking Union Medical College's Institutional Ethics Board approved all study protocols. Prior to the study, written informed consent was obtained from all subjects. All samples of blood from each group were used for the study of biomarkers. Samples of semen were used in routine semen analyses and in the comet assay.