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Metal exposures from aluminum cookware: An unrecognized public health risk in developing countries

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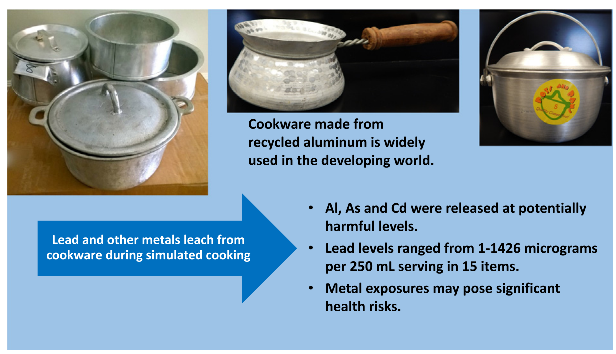
HIGHLIGHTS

- Inexpensive aluminum cookware is widely used throughout the developing world.
- Cookware from ten developing countries was tested for the leaching of toxic metals.
- Simulated cooking leached up to 1426 micrograms of lead per 250 mL serving.
- Al, As and Cd were present in some leachates at potentially harmful levels.
- Exposure to metals by corrosion of cookware may pose significant public health risks.

GRAPHICAL ABSTRACT



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ABSTRACT

Removing lead from gasoline has resulted in decreases in blood lead levels in most of the world, but blood lead levels remain elevated in low and middle-income countries compared to more developed countries. Several reasons for this difference have been investigated, but few studies have examined the potential contribution from locally-made aluminum cookware. In a previous study of cookware from a single African country, Cameroon, artisanal aluminum cookware that is made from scrap metal released significant quantities of lead. In this study, 42 intact aluminum cookware items from ten developing countries were tested for their potential to release lead and other metals during cooking. Fifteen items released ≥1 microgram of lead per serving (250 mL) when tested by boiling with dilute acetic acid for 2 h. One pot, from Viet Nam, released 33, 1126 and 1426 micrograms per serving in successive tests. Ten samples released >1 microgram of cadmium per serving, and fifteen items released >1 microgram of arsenic per serving. The mean exposure estimate for aluminum was 125 mg per serving, more than six times the World Health Organization's Provisional Tolerable Weekly Intake of 20 mg/day for a 70 kg adult, and 40 of 42 items tested exceeded this level. We conducted preliminary assessments of three

Abbreviations: ICP, Inductively coupled plasma spectrometry; MADL, Maximum allowable dose level; PTTIL, Provisional tolerable total intake level; PTWI, Provisional tolerable weekly intake; UL, Tolerable upper intake level; XRF, X-ray fluorescence.

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Cookware
Developing countries

potential methods to reduce metal leaching from this cookware. Coating the cookware reduced aluminum exposure per serving by >98%, and similar reductions were seen for other metals as well. Potential exposure to metals by corrosion during cooking may pose a significant and largely unrecognized public health risk which deserves urgent attention.

1. Introduction

A wide variety of aluminum cookware and utensils are used throughout the world. Much of this cookware is locally made, uncoated and not anodized. Previous investigations indicated that in Cameroon, some of this cookware is made in informal shops by casting liquid aluminum melted from a collection of scrap metal (Osborn, 2009; Weidenhamer et al., 2014). Other studies have reported on the potential leaching of metals from aluminum cookware in India, Egypt, China, Saudi Arabia, Syria, and Bangladesh (Al Juhaiman, 2012; Bergkvist et al., 2010; Mohammad et al., 2011). In this study, we evaluate the potential for aluminum cookware from additional countries to contribute to metal exposures through normal cooking.

Despite the removal of lead additives from gasoline more than a decade ago in all but a small number of countries, numerous recent reports document the widespread persistence of elevated blood lead levels in low and middle-income countries (El-Desoky et al., 2013; Kalra et al., 2013; Kapitsinou et al., 2015; Li et al., 2014; Naicker et al., 2013; Swaddiwudhipong et al., 2013; Tuakuila et al., 2013; Xie et al., 2013). There is no safe level of lead exposure (CDC, 2012; Lanphear et al., 2005; Wigle and Lanphear, 2005). The toxic effects of lead are well known. Lead exposures are linked to learning disabilities, attention-related behaviors, deficits in intellectual development, high blood pressure and cardiovascular disease. The estimated global toll from lead poisoning is 674,000 premature deaths annually (Lim et al., 2012) and economic costs approaching $1 trillion (Attina and Trasande, 2013). The persistence of elevated blood lead levels in much of the world is therefore of great concern for public health and economic development.

Lead consumption is growing rapidly around the world primarily for the production of lead batteries. Emissions from the manufacturing and recycling of these batteries have been documented to contribute to lead exposures in populations surrounding these plants (Gottesfeld and Pokhrel, 2011). In addition, a wide variety of consumer products contain lead additives including lead paint that is commonly used in at least 40 countries around the world (Clark et al., 2009, 2015; Gottesfeld et al., 2013, 2014; Kumar and Gottesfeld, 2008; Occupational Knowledge International, 2016). Other consumer products that contain lead and are often unregulated include plastics, lipsticks, jewelry, solder, brass, and ceramic glazes (e.g. Gilmore et al., 2013; Weidenhamer and Clement, 2007; Zhao et al., 2016).

Locally-made aluminum cookware is a potential source of lead exposure that has largely been overlooked. This cookware is widely used throughout the developing world (Al Juhaiman, 2012; Al Zubaidy et al., 2011; Bergkvist et al., 2010; Osborn, 2009). The potential for metals to leach from this type of cookware has been studied previously, but typically with a focus on potential hazards of aluminum (e.g. Al Juhaiman, 2010, 2012, 2016; Inoue et al., 1988; Karbouj et al., 2009; Mohammad et al., 2011). Previously we reported (Weidenhamer et al., 2014) that cookware items manufactured by local artisans in Cameroon pose a significant risk from the leaching of multiple metals during cooking. Investigations in that country revealed that scrap metal was the primary source material for this cookware including waste engine parts, vehicle radiators, lead batteries, computer parts, and other materials. Potential lead exposures from cooking were estimated to be as high as 260 μg per serving, indicating a serious potential health hazard. In addition, simulated cooking in the laboratory released significant concentrations of other metals. Up to 15.6 μg Cd was released per serving, and all items tested released aluminum in amounts per serving which exceeded the provisional tolerable total intake level (PTWI) for aluminum of 140 mg/person/week or 20 mg/person/day for a 70 kg adult (WHO, 2011b). Because of the widespread use of inexpensive aluminum cookware in many countries (e.g. Osborn, 2009), determining the extent of metal exposures from this source and evaluating potential solutions is an urgent need.

Our objective in this investigation was to explore how widespread the potential health risks posed by aluminum cookware may be in the developing world. We obtained and tested 42 intact aluminum cookware items from ten developing countries in Asia, Africa and Central America for their potential to release lead and other metals during cooking. We also conducted preliminary studies on possible means to reduce corrosion of the cookware and thereby reduce metal exposures.

2. Methodology

2.1. Sample collection

Forty-two cookware samples were collected from ten countries (Bangladesh, Guatemala, India, Indonesia, Ivory Coast, Kenya, Nepal, the Philippines, Tanzania and Viet Nam). The majority were new items, and varied in appearance (Fig. 1). All were locally manufactured and available for purchase in the country. Half (21 of 42 samples) from five countries (Bangladesh, India, Indonesia, the Philippines, and Viet Nam) indicated brands on labels or commercial logos imprinted on the pots when received for analysis.

2.2. X-ray fluorescence (XRF) analysis

XRF screening of cookware samples was conducted using a Niton XL3t GOLDD XRF spectrometer (Thermo Fisher Scientific, Billerica, MA). Prior to analysis, an internal system calibration was performed. Samples were analyzed for metals in "general metals" mode using an aluminum alloy (grade 6061) reference material.

2.3. Leaching tests

There is no standardized method to replicate normal cooking for the measurement of metals leaching from aluminum cookware. Here, we used a 2 h boiling extraction with dilute acetic acid (4% vol/vol), an extraction which simulates cooking with weakly acidic foods such as tomato sauce (Al Zubaidy et al., 2011; Inoue et al., 1988; Mohammad et al., 2011; Weidenhamer et al., 2014).

Volumetric flasks and all other glassware used in these experiments were rigorously acid-washed with concentrated nitric acid prior to analysis. All cookware was washed with soap and water prior to undertaking these experiments.

Samples were leached with 4% acetic acid (vol/vol) for 2 h in boiling solutions. Cookware was filled to within 1 cm of the rim, and brought to a gentle boil on a hotplate. Pots that had curved rather than flat bottoms were heated over natural gas burners. For pots which did not have lids, glass plates were placed on top of the pots to retard evaporation. The samples were then boiled for 2 h, during which time 4% acetic acid was added as needed to maintain solution volumes. After cooling, solutions were transferred directly to 50 mL polyethylene test tubes and stored under refrigeration until analysis.

The test procedure was repeated for fifteen of the pots to determine the consistency of metal concentrations released by corrosion during