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Mercury Exposure and Potential Risks from Rice-based Infant Foods in Infants: A Literature Review

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Abstract

Rice-based infant cereals and snacks are popular starter and weaning foods for infants around the world. Recent research has indicated that rice can accumulate a variety of heavy metals, with mercury posing the biggest risk to human health. During manufacturing and processing of infant foods, these heavy metals are not removed, thus causing increased incidence of exposure. Mercury and heavy metal exposure in infants is significantly more detrimental than in adults and can cause physical and neurocognitive developmental defects. This literature review evaluated 97 sources found through PubMed and Google Scholar to determine the prevalence of mercury and heavy metals in rice-based infant foods. In conclusion, multiple studies showed the continued presence of these contaminants in rice-based infant foods along with how exposure can cause long term side effects in infants. Further studies are warranted to evaluate mercury levels in certain brands of infant foods and to determine if there is a statistically significant difference in mercury levels of organic vs. non-organic infant foods.

Keywords: Rice-based infant foods; Infant cereal; Mercury in rice; Heavy metals; Infant development; Arsenic; Mercury; Methylmercury; Cadmium

Introduction

We review the occurrences of heavy metals in rice-based infant foods. Heavy metals discussed include arsenic (As), lead (Pb), cadmium (Cd), copper (Cu), mercury (Hg) and zinc (Zn). Heavy metals are consistently found in rice plants as heavy metal compounds are easily transported through soil, atmosphere, and irrigation systems [1-4]. Rice is frequently consumed as a carbohydrate source and can act as a transitional meal for infants when weaning from breast milk in many countries [5]. When rice is processed into rice-based infant food, heavy metals within the rice grains can be transferred into the infant food. This can be harmful, especially since infants are more susceptible to heavy metals due to their body weight and relative intake [6-8]. Negative effects of heavy metal exposure in infancy can include cognitive, neurological and physical developmental delays and the possibility of continued problems in their future life. Few definitive studies have been published which report the detrimental impacts of initial heavy metal exposure in infants throughout adult life. [9-13].

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Mercury and Heavy Metals in Rice

Central and East Asia are responsible for producing 90% of the world's rice supply [14-16]. Due to the proximity of Asian agricultural areas to metal mines, coal burning power plants and busy highways, heavy metal accumulation within rice plants continues to be a persistent problem [17, 18, 96]. These heavy metals have a range of benign and malignant effects on the human body, including damage to the central nervous system from exposure to both lead and mercury [20-21]. Toxic effects can be significantly more pronounced and detrimental in infants and young children [22-24]. Detailed investigation into the species and concentrations of heavy metals within rice plants persists as a significant issue in the agricultural and global health communities [25-26].

Asian agricultural areas that have arisen around active or recently inactive metal mining regions seem to contribute a large portion of heavy metals to rice paddies [17, 27]. Waste from mining activities can pollute local soil and water supply, causing heavy metals to seep into rice crops through irrigation systems [28]. Heavy metal contaminated water is commonly not processed at treatment plants to remove pollutants and therefore has a higher chance of polluting rice crops downstream [29]. In India, it was shown that rice had less heavy metals than vegetables due to contaminated irrigation, but there was still a potential human health risk due to the high content of rice-based foods in the population's diet [29-30]. Electronic waste (e-waste) comparatively has a high contamination risk potential because many companies use primitive methods to recycle their waste, leading to waste dumping into the local water supply [31-32]. In China, rice samples that were taken from e-waste areas were three times higher in heavy metal concentrations than the control market samples [31,33]. Levels of heavy metals in the consumable portion of rice plants continues to be a topic of discussion and warrants further investigation into how exposure affects human physiology along with ways to prevent pollution and accumulation of these metals in the environment.

Arsenic

Arsenic is primarily known as an accidental contaminant and presents itself in several different forms which vary in toxicity. For example, inorganic forms are found to be much more toxic than organic forms [34]. Arsenic more readily accumulates in the rice grain when there is soil contamination from anthropogenic activities such as mining and its associated waste disposal [35-36]. This is likely due to chemical similarity between silicon and arsenic, which allows arsenic to utilize the naturally present silicon transporters within the rice plant [17].

Lead

Lead ranks as a top priority for agricultural management due to its significant health implications. Exposure to lead can come from a variety of sources, including water piping, cosmetics and other consumer goods and from certain objects some people encounter at work, like construction materials [37]. Lead found in paint and gasoline can easily transfer from the air to the plant or the soil [38-40]. Due to this, living within a certain distance from an airport can increase environmental exposure to lead, especially in children [37]. Rice paddies in areas of high traffic display higher lead levels as air pollution allows for atmospheric uptake into the leaves of the rice plant [41]. Translocation mechanisms of the rice plant allow lead to migrate to the grain, which is subsequently harvested for human consumption [18]. Contaminants from fossil fuel emissions can also be deposited directly into the soil of rice crops [42].

Cadmium

Cadmium is known as a renal, reproductive and neurotoxin [43-44]. Even though it is an unnecessary element for plant growth, Cadmium is very mobile and gets easily absorbed and transported to the grain portion [45]. In southeastern Asia, rice intake is the primary source of cadmium exposure [42,46]. In contaminated soils, cadmium accumulation increased as the rice plant matured and there is significant evidence that cadmium found in the grain portion is from remobilized cadmium originally found in the leaves [42,47].

Mercury

The main introductory mechanism of mercury, which is considered a neurotoxin, into the rice plant is through microbial methylation of inorganic mercury that naturally resides in the soil of rice paddies. During initial investigation into mercury accumulation in rice, concerns over the use of toxic, mercury-containing fungicides were being called into question [48]. Different species of mercury provide different methylation potential, with mercuric chloride being the most likely to be methylated [49]. This compound causes concern for human health as it has a significant potential for transport and accumulation within the rice grain itself [49]. Additionally, inorganic mercury is easily methylated in the gut of earthworms, where the appropriate anaerobic conditions are available [50].

Heavy metals in infant foods

Rice is a common source of dietary heavy metals as the plant has the capability to uptake environmental contaminants along with its necessary nutrients from the soil and water supply [51]. Contaminated rice is harvested and used to mass-produce a variety of foods, including rice-based infant foods. After breast milk, most infants' main source of carbohydrates is infant cereals and foods, which are primarily made from rice [52-53]. This increases their likelihood of exposure to heavy metals [54-55]. Arsenic is a frequent contaminant in rice-based food since rice has an increased capability to uptake arsenic compared to other carbohydrate sources, like oat and barley [56]. In Poland, a study evaluated levels in rice and infant rice-based foods found that the content of arsenic in ⅔ of the tested samples of rice exceeded pre-determined limitations [57]. Specific to types of rice-based products, levels of arsenic were within limits except for rice wafers, possibly due to the higher concentration of rice content within the product [57]. This is correlated with rice being listed as the first ingredient in infant food items, indicating a greater amount of arsenic in that food [56,58]. When testing for cadmium levels in baby food, there was only 1 sample that exceeded the testing limits, but values determined were still within FDA guidelines [43]. Zinc and lead are also commonly traced in infant formula and baby weaning food, which are used after infants stop breastfeeding. In the rice-based foods, zinc and lead were found in higher concentrations compared to infant formula, but still within limits [59]. Overall, zinc and lead levels were within normal limits in all the tested formulas, but it is important to be cautious [59]. One reason most rice-based infant foods had smaller amounts of heavy metals compared to plain rice could be that a large majority of rice-based infant foods are mixed with whey, wheat and other compounds during production [56]. Heavy metals are not found in significant amounts in infant foods due to lack of testing, but it is important to be aware of their effects in trace quantities [60]. For some populations, even a small amount of a heavy metal exposure can have deleterious side effects and there is no "safe limit" for heavy metal consumption [61].

Mercury in rice-based infant food

There are many different forms of mercury, with organic forms considered to be the most toxic. Methylmercury (MeHg) is a subset of organic mercury that is found in rice, fish, and rice plants [62]. Methylmercury is frequently found in run-off waste in water, atmospheric deposition, and in fertilizer [63]. In run-off water, methylmercury can easily be converted between multiple forms and can also be found in rainwater, which will eventually end up in soil [64]. Methylmercury is also bio-accumulated by rice plants through the soil, as demonstrated by a study that found that rice plants contained higher levels of methylmercury than the soil surrounding them [65]. Growing rice aerobically, however, was shown to lower the content of methylmercury [66]. It is displayed that the methylmercury levels in rice-based cereals were higher than in cereals without any rice [67-68]. Levels amongst products could vary due to the fact that most of the methylmercury is found in the hull and bran of the rice, which is normally removed when polishing and then used for rice-based cereal foods [67].

Within the rice-based cereal foods, there is a difference in methylmercury intake [69]. For example, teething biscuits have an average of 0.0066 micrograms of methylmercury per serving compared to 0.0092 micrograms per serving of rice baby cereal [68]. This means that more servings of teething biscuits must be consumed to obtain the same amount of methylmercury levels as the infant cereal. There is also a difference of methylmercury levels in products within different manufacturing countries. In a study in Argentina, methylmercury and several other heavy metals were scanned for in infant cereal, rice noodles, and other rice-based products, and concluded that no methylmercury was found in any of the samples [70]. Compared to China, where it was seen that small ratios of methylmercury and heavy metals were seen in higher larger numbers of rice plants themselves [42]. This can be transferred into any infant products made with this rice. These differences in methylmercury content between products could primarily be due to different soil conditions in each country. These results show that methylmercury must be closely monitored in rice-based infant foods, especially when it is used as a primary source of carbohydrates for the child [71]. Knowing that infants are more susceptible to the harmful effects of methylmercury, accurately screening for methylmercury content in these foods is important [71].

Outstanding factors

Outstanding factors can also affect the levels of methylmercury in rice-based infant foods. Some of these include fish quantity, organic processing, and gluten-free foods [72-74]. Rice-based infant foods that include fish have higher levels of methylmercury compared to rice-based infant foods without, especially because fish is the primary source of methylmercury in humans and infants [75-76]. A study in Portugal concluded that processed cereal foods contained a median level of 0.5 and 0.4 micrograms of methylmercury was found in processed cereal foods while fish based infant foods contained 19.56 micrograms of methylmercury [77]. Organic rice-based infant foods have also been shown to contain a higher concentration of methylmercury than non-organic products [73]. Most organic foods include the hull and bran of rice as well as the starchy endosperm, increasing the methylmercury content. This would indicate the need for manufacturers who produce organic rice-based infant foods to have stronger quality and purity checks for their products. Increase in methylmercury levels in rice-based cereals could be cause for concern in infants with celiac disease since most rice-based products are labeled as gluten-free [68]. Instead celiac patients should attempt to consume products made of oats rather than rice, to decrease the potential of contact with methylmercury contaminated products while maintaining abstinence from gluten [78].

Effect of mercury and heavy metals on childhood development

Since methylmercury is not susceptible to environmental degradation, it makes it easier to pass biological barriers in humans through consumption of rice and rice products [79]. Some of these barriers include the blood-brain barrier, placenta and blood-testis barrier [79-80]. Mercury uptake in humans can cause a slew of problems including central nervous system toxicity and gastrointestinal effects [81].

Neurocognitive Development

Neurocognitive development of children, especially young children, can be impacted by a multitude of environmental stimuli. These can include various dietary regimens, availability and access to quality education and, as is discussed in this paper, exposure to different environmental toxins, such as heavy metals [82]. Due to mercury's more severe effects on the central nervous system in infants, exposure can lead to poor memory ability, speech delay and worsened academic performance [67]. Kim et al. evaluated the effect of heavy metal and other environmental pollution exposure in 1-2-year olds. They discussed that exposure to certain endocrine-disrupting chemicals, like lead and mercury, had a negative impact on a toddler's neurodevelopment and were additionally associated with behavioral and sleep problems [83]. When investigating the development of ADHD/ADD in school-aged children, discussions of eliminating lead, cadmium, and antimony from a child's diet is controversially being recommended as a prevention method [84]. At this current time, there is not any significant data to indicate this would be an effective or safe course of action.

Physical Development

In addition to neurocognitive defects initiated by intake of heavy metals, physical development can be negatively impacted by certain heavy metals, specifically lead, arsenic and cadmium [22]. In a 2017 study, Choi et al determined that post-birth weight gain and current head circumference of infants was negatively correlated with increased levels of lead and arsenic [97]. In certain circumstances, the possible detrimental effects of prenatal and postnatal exposure to heavy metals, notably methylmercury, can be outweighed by the benefits of other nutrients obtained from contaminated sources [85]. In-utero, long-chain polyunsaturated fatty acids obtained from maternal ingestion of fish, mostly fish at the top of the food chain, supports brain and nervous system development [86]. Additional pre- and postnatal exposures to mercury, including vaccination stabilizers and dental amalgams, along with fish consumption, are believed to be less concerning when compared to the risk of a child not receiving complete vaccination, optimal dental care and proper nutrition [87]. The risk-benefit analysis of fetal exposure to methylmercury vs. providing the necessary nutrients for essential brain development is inconclusive. A 2009 study by Myers et al. reports that mercury poisoning can cause diffuse brain damage in an infant, as it causes oxidative damage and alters the anabolic pathways needed for protein synthesis [88]. Methylmercury can be passed on from mother to infant through breast milk as a result of the mother's eating habits, which could include fish and rice-based foods. This is due to methylmercury's lipophilic capabilities [89]. An interesting aspect of increased maternal mercury exposure, leading to fetal exposure, is the likelihood that the mother is going to have dental cavity requiring intervention with an amalgam. Approximately 95% of pregnant people will have a cavity throughout the duration of their pregnancy [90]. Upon placement and/or removal of a dental amalgam, the incidence of vaporization of mercury contained within the filling increases significantly [91]. Drasch et. al found a correlation between mothers with an increased number of amalgams and increased fetal blood concentration of Hg upon fetal autopsy [92-93].

The investigation into long term effects of maternal MeHg exposure and postnatal MeHg exposure are not well studied, especially when discussing scholastic and academic achievement [94]. In a 2010 study by Davidson et al, it was determined that prenatal exposure to MeHg via high maternal consumption of fish caused no statistically significant detriments to academic performance later in the child's life. However, there was an association between postnatal MeHg exposure and worse academic outcomes in males only. Vahter et al in 2007 believes this can likely be attributed to males having a higher cognitive sensitivity to neurotoxic heavy metal deposition along with differences in metabolic functioning to process and eliminate MeHg compared to their female counterparts [95].

Future Studies

The presence of heavy metals, notably mercury, in rice-based baby foods continues to be an important topic of investigation and necessitates deeper dissection to determine health guidelines for parents and their babies. Current data indicates that fetal and infant exposure to mercury through diet and maternal routes of fetal uptake through the placenta and breastfeeding can be associated with significant neurodevelopment and physical defects, especially in those with more rice-based diets. Children with rice-based diets would include those living in Asian countries and those who are intolerant to gluten, such as a child with the diagnosis of Celiac's disease [96]. Rice-based infant cereals are additionally a popular source of nutrition and sustenance for infants within the United States as these products are frequently used for weaning. These concepts introduce multiple, significant areas for further research.

In the United States, Gerber is the commonly purchased brand of baby food as they provide age-appropriate food for infants, toddlers and young children. Many of their infant foods are rice-based, which brings up the concern of exposure to Hg and other heavy metals that have been discussed in this paper. A future study to help direct purchasing of infant foods can involve direct comparison of best-selling infant food brands, including Gerber, Beech-Nut, Happy Baby Organics, Nestles and Stonyfield Organics, specifically analyzing their rice-based products to determine the quality of the product via Hg and heavy metal concentration determination.

According to a 2017 study by Rothenberg et al, Hg levels in rice-based infant cereals was significantly higher than the Hg content found in rice-based teething biscuits [68]. This is particularly important when these products are being used for weaning, as the infant is still receiving some of their nutrition from breast-feeding, which can also be a source of maternal-infant Hg exposure. To further evaluate the possible danger posed from this increased Hg exposure, determining the Hg content in different rice-based baby foods such as cereals, snacking puffs, teething biscuits and rice rucks, and comparing them to each other will provide valuable information for mothers of what is safest to provide their weaning baby.

Nearly all companies manufacturing rice-based baby foods provide the location of physical manufacturing of the product as well as where the rice that the product contains came from. This information is usually found either on the brand website or on the back of the physical packaging found in the store. As discussed above, rice harvested from different areas of the world will have varying levels of Hg contained within the grain. Particularly, rice that is harvested from Asian regions near mines, heavy traffic, and other forms of pollution are associated with high levels of Hg [69]. A future study regarding this topic could involve purchasing rice-based infant foods from a local grocery store, determining the region the rice was procured from and analyzing the Hg content between the products. This can provide information for manufacturers and brands if a pattern of higher Hg content arises from one specific geographic region.

As discussed in a detailed study by Hernandez-Martinez et al in 2013, organic infant cereals were found to have a higher percentage of Hg compared to their non-organic counterparts [73]. They suggested that this was due to the addition of both cocoa and rice to the organic products. An appropriate future study to delve deeper into the findings of this paper and the information provided by the 2013 study would be identify organic infant cereal brands currently on the market that have the highest concentration of Hg and determine the primary source of Hg to provide a succinct and parent-friendly guide to which foods will be safest to feed their babies. This analysis can be done in conjunction with the brand analysis as previously mentioned.

Conclusion

As a primary source of carbohydrates after breastfeeding and formula, infants are given cereals and snacks that are rice-based. These snacks could potentially have a high amount of mercury and other heavy metal contaminants that could lead to neurological, physical and cognitive developmental issues. Much of the research discussed in this review has shown that there are heavy metal contaminants in rice plants and rice-based infant foods. There are also several studies showcasing the long-term, severe side effects of heavy metal poisoning in infants and the way it can impair cognitive development. This review suggests that increased screening of rice-based infant foods is required in order to confirm the safety of the product and its consumption. This can be done through monitoring the growth of the rice that is used for the cereal and snack products as well as doing a secondary, thorough check after the product is made. Additional studies are needed in order to thoroughly evaluate the amount of mercury in rice-based infant foods and whether it is found at higher concentrations in certain brands or in organic food compared to regular products.

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