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Pediatric Cadmium Toxicity in America:
Exploring Everyday Exposure Risk for Cavities and Decreased Neurodevelopment

Just two years ago, parents were shocked to find that their children were playing with jewelry and toys tainted with the seventh most hazardous chemical, cadmium. People were enraged because ten million popular McDonalds Shrek happy meals were recalled since they had traces of this toxin. Dyes on trendy Shrek glasses were laced with deadly cadmium, which could be readily ingested by children. Parents were appalled by product recalls from large retailers like Claire's Walmart, Dress Barn, Justice and Limited Too. With increasing restrictions on lead, Chinese manufacturers swapped cadmium for lead in their products to maintain profits. In order to protect their children's health in the future, parents demanded to know why cadmium showed up in mainstream children's items. The petitioners requested the Environmental Protection Agency (EPA) to regulate cadmium in children's products and provide health and safety data. Despite their efforts, today there still is no regulation of cadmium in children's toys. Parents have to settle with just recommended daily intake information on a toxin more lethal than lead (Mead, A528-34).

Cadmium is a large threat, especially to vulnerable, developing children, because it is so easy and cheap to find. Cadmium is naturally found as an impurity trapped in iron and zinc rocks. With the technological era today, cadmium is released as a byproduct while smelting virtually any metal (iCdA, 4). Manufacturers usually use cadmium to give products an attractive metallic shine and durability that most other metals just cannot bring at the low cost. Ironically, cadmium's metallic properties and availability have been taken advantage of in green technology: solar cells and electric car engines. Cadmium is likely to find itself in more products in the future since its properties make it so valuable (Tolcin, 36-44). However, as cadmium increases in the products people just cannot live without, so does the toxic threat it carries along with it.

Scientists have found that cadmium affects children's dental and neurological health. Cadmium can be absorbed in teeth, especially in children, whose teeth are softer since they are still developing (Bayo *et al.,* 247). Ultimately, cadmium exposure can result in tooth decay or cavities. Epidemiological studies show children with high cadmium exposure were reported with mental retardation, learning difficulties like dyslexia, motor and perceptual abilities, and decreased IQ (Cao *et al.,* 1580). Since cadmium is such a deadly toxin, it is important to understand the extent of damage it can do to children. This study explores the extent to which the environmental exposure to the metal toxin, cadmium, affects teeth and neurodevelopment in children. Cadmium can cause the body to decrease the absorption of calcium forming kidney stones, increase aging and pass on the toxicity to newborn babies via breast milk. The cadmium threat is increasing due to increased demand for cadmium, zinc and iron. We can tackle this threat by recycling electronic waste (e-waste).

Cadmium is an increasing threat to American children because it affects their teeth and neurological development, but which cadmium toxicity consequence should parents worry about more? One side of the debate, cadmium's affect on pediatric dental health, is primarily informed by two research articles: "Association of Environmental Cadmium Exposure with Pediatric Dental Caries" by Dr. Manish Arora and "Environmental and Physiological Factors Affecting Lead and Cadmium Levels in Deciduous Teeth" by Dr. J. Bayo. Dr. Arora, who does research at Harvard School of Public Health, published that there was a statistically significant relationship between cadmium exposure in children ages 6-12 and cavities. He and his research colleagues suggest that cavities are such a common disease that is affected by a variety of environmental factors, such as heavy metal poisoning, that children have no control over. In addition, cadmium was related to permanent severe tooth decay, which could not be reverted, even with fluoride treatments (Arora *et al*., 821). Dr. Bayo and his research associates, who work in Technical University in Cartagena, Spain, build on Dr. Manish Arora's work by delving into how cadmium affects the teeth. Using milk teeth, Dr. Bayo found that cadmium replaces crystals of dentin, making up the toughest part of the tooth (Bayo *et al.,* 247).

The opposing viewpoint, cadmium affects pediatric neurological development more than pediatric dental health, is primarily informed by "Postnatal Cadmium Exposure, Neurodevelopment, and Blood Pressure in Children at 2, 5, and 7 Years of Age" by Dr. Yang Cao and "Developmental Neurotoxicants in E-Waste: An Emerging Health Concern" by Dr. Aimen Chen. Dr. Chen, who works in the Department of Environmental Health in the University of Cincinnati College of Medicine, found that cadmium exposure decreased intelligence and neuropsychological functions by 60% (Chen *et al.,* 435). Dr. Cao, who is a health statistician in Shanghai, worked with Dr. Chen to find cadmium exposure ultimately results in mental retardation, dyslexia, and lowered IQ by disrupting signaling in the nervous system. (Cao *et al.,* 1585)

This research study examines whether cadmium has a more significant impact on pediatric cavities or neurodevelopment. In order to understand cadmium's impact on toddlers, many questions need to be asked: What is the mechanism of cadmium uptake? What is the worst-case scenario of cadmium toxicity on dental and neurological health? Is the prevalence of cavities higher or lower than acute neurological disorder? What are the long-term health effects of cadmium toxicity? What is the trend of this toxin in our environment? Finally, how can we address this growing threat?

The mechanism for cadmium uptake is unknown, but scientists found key steps. Cadmium can enter the body quickly via inhalation, contact or consumption. Once in the body, cadmium replaces essential nutrients. In order to understand cadmium toxicity, the pathway where cadmium is most readily absorbed must be identified: inhalation, contact or consumption. The EPA does not regulate cadmium in merchandize because cadmium is most dangerous when inhaled, not consumed or contacted. Statisticians considered dermal exposure insignificant when analyzing cadmium exposure risk, “It is widely accepted that approximately 2% to 6% of the cadmium ingested is actually taken up into the body. In contrast, from 30% to 64% of inhaled cadmium is absorbed by the body” (iCdA 4). Based on the statistician’s analysis, inhaling cadmium is 5 times more likely to be deadly than consumption or contact.

Therefore, children inhale cadmium primarily from second hand smoke because tobacco has notoriously high cadmium levels. The Occupational Safety and Health Administration (OSHA) analyzes why cadmium inhalation is more lethal than contact or ingestion, “Inhaled cadmium is more readily absorbed into the body than is ingested cadmium.” (OSHA 5). Based on OSHA’s analysis, inhalation is the quickest route for distribution of the toxin throughout the body. Toxins are readily absorbed into the respiratory tract, which has very few defensive mechanisms compared to contact or ingestion. The skin has many layers, which make it more difficult and longer to penetrate. The digestive system has harsh acidic environments, a strong defensive mechanism against toxins like cadmium.

Furthermore, cadmium wreaks havoc because it can be mistaken as an essential nutrient when it is absorbed in the body. Cadmium is mistakenly taken up instead of essential nutrients because they both have a +2 charge. Essential nutrients include calcium, magnesium, sodium, phosphorus, iron, and zinc. An experiment found the relationship between cadmium and calcium, using data on mothers who smoked cigarettes, which have notoriously high cadmium levels, "One German study showed a direct relationship between the level of cadmium and other +2 oxidation state nutrients. They found the uptake of calcium decreased most" (Lah 1).

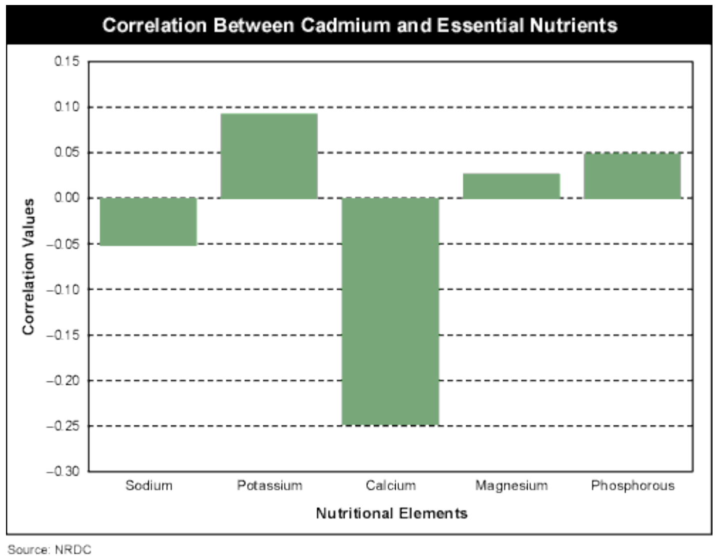

Figure 1 Correlation between Cadmium and Calcium

Figure 1 depicts the correlation between calcium and cadmium is -0.25, from the German study. This means cadmium decreases calcium uptake more than any other nutrient.

Moreover, the rate cadmium replaces calcium increases in nutrient deficient children. For example, cadmium uptake is optimized, when iron, an essential nutrient that can be replaced by cadmium, is deficient, "Chronic nutrient deficiency can result in up regulation of systems to optimize uptake of the missing nutriments, and cadmium may be opportunistically taken up via some of these systems" (Mead A530). Cadmium can be mistaken as iron since both have the same charge. When a person is iron- deficient, the body is desperate for iron and more likely to absorb cadmium, erroneously.

Cadmium replaces essential nutrients, which has roles in both teeth structure and sending messages in the nervous system. In order to assess whether dental or neurological health is more affected by cadmium toxicity: (1) we will need to understand how cadmium impacts dental and neurological health at the molecular level; (2) We will need to compare incidences of the worst-case scenarios of cadmium's affect on dental and neurological health. Scientists agree that many heavy metals, including cadmium, impact dentin, which is a major structural component in teeth. "Heavy metals are known to substitute for calcium in the hydroxyapatite crystals of dentin, a calcifying tissue that, unlike bone, once formed remodels very slowly" (Bayo et al 247). By replacing calcium in teeth, cadmium stays and accumulates in the mouth for the rest of the child's life.

On the other hand, cadmium has serious effects on the nervous system by interfering with calcium's function. Cadmium affects neurotransmission by disrupting the calcium-signaling pathway, **"**Cd exposure may modify calcium channels and decrease the release of neurotransmitters into the synaptic clefts" (Chen et al 435). Calcium channels are very specific and only allow calcium to flow through. When cadmium is mistaken for calcium, the channel is modified in order to accommodate cadmium. This modification prevents calcium from passing through the channel. Without calcium, signals cannot be sent from the brain to the rest of the body. There will be a delayed response, as other parts of the nervous system, which have less cadmium damage, get the message across.

Scientists have studied the worst effect of cadmium exposure on the nervous system, acute brain disorder, "…There has been a single case report of cadmium encephalopathy in a 2-year-old child**"** (Cao et al 1585). Although there are many cases of decreased neurological development, there was only one reported case of acute brain disorder caused by cadmium. There is only 1 case of brain disorder because the blood brain barrier prevents high-level cadmium toxicity. Cadmium can only pass the barrier in very small doses undetected and accumulate within the brain. However, this scenario is unlikely because our brain has a very efficient defensive mechanism against toxins.

Based on the worst possible outcome of cadmium toxicity in both dental and neurological health, cadmium's effect on dentin in teeth is more threatening, "Dental caries is the most common chronic childhood disease in the United States. The prevalence of dental caries exceeds 50% in 5- to 9-year-old U.S. children and increases to 78% in those 17 years of age." (Arora *et al.,* 821). Since teeth are externalized and the nervous system is internalized, it is more likely that cadmium will increase cavities by 28%. In addition, people only shed their teeth once in a lifetime. Once permanent teeth are gone, there is no way for the body does to repair or limit the damage. However, if a calcium channel is blocked, there are other calcium channels that can be used to send the message, although it will be delayed.

In addition to detrimental impacts on dental and neurological health, cadmium has additional long-term effects such as kidney stone formation, aging and passing toxicity on to children. These long-term effects arise from cadmium's long half-life and overexposure from trace toxin amounts. Regulation in factories has increased due to cadmium's health effects, "Due to its low permissible exposure limit (PEL), overexposures may occur even in situations where trace quantities of cadmium are found in the parent ore or smelter dust" (OSHA 1). Overexposure for cadmium is 5 micrograms (OSHA). In perspective, cadmium exposure can be equated to approximately 1 out of 1,000,000 pounds. It would take 1-2 weeks of eating contaminated food to be overexposed for an adult. It would take only 3 days to be overexposed with smoking cadmium-contaminated cigarettes for an adult.

However, since most people are not exposed to cadmium on a regular basis, accumulating substantial amounts of cadmium would take decades. For vulnerable children, the length of overexposure is less, “The problem with children is that they take up cadmium more readily than adults, and their organs are smaller. They don’t need a ‘head start’ in accumulation” (Mead A531). Cadmium is much more dangerous to children since it will affect their developing structure. Since the dentin is softer in children’s teeth, cadmium is more readily absorbed. In proportion with adults, it would take much less cadmium for a child to be considered overexposed.

Due to cadmium, the flawed structure stays in a child’s body for the rest of his or her life. Scientists have calculated the half-life, the time for half of the toxin to degrade, “Once cadmium enters the body, it has a biological half-life of 10-30 years in kidney” (Cao et al 1580). Since only trace amounts cause significant toxic effects, once cadmium is absorbed it stays in the body for the rest of a human’s life, due to the long half-life. Hence, cadmium would accumulate in teeth and the nervous system until death.

Cadmium affects teeth and the nervous system permanently by replacing calcium. If calcium is not absorbed by teeth and used to send messages in the nervous system, then the body excretes it. A case study offers data on men exposed to cadmium and their kidney activity, “In men exposed to cadmium for between six and 10 years, 12% had renal stones.” (Kennedy 313). A substantial amount of people had kidney stones because when calcium is about to be excreted, it accumulates in the kidney. This accumulation starts the formation of kidney stones after long-term exposure to cadmium.

With cadmium accumulation, many biological pathways would be interrupted. Scientists explain how cadmium interrupts the body’s function with reactive oxygen species; “Heavy metals can induce oxidative stress by increasing the production of reactive oxygen species (ROS) and depletion of antioxidant reserves” (Chen et al 435). Reactive oxygen species are harmful species that can invade most parts of the body, wreaking havoc. These species increase the rate of aging, which explains why people support antioxidants for preserving youth.

Not only can cadmium affect the current generation, but it can also affect future offspring. Toxicity passed from mother to baby with breast milk is arguably a long-term effect of greater concern, “This may be especially important for females because it is a potential endogenous source of lead that will be released during pregnancy and lactation” (Bayo et al 247). When women breastfeed, their children and ingest cadmium and start accumulating it at such a young age. Cadmium can cause the body to decrease the absorption of calcium forming kidney stones, increase aging and pass on the toxicity to newborn babies via breast milk.

Cadmium is speculated to be an increasing threat to children’s health due to e-waste, nickel-cadmium battery demand and other metal demand increasing trends. 82% of electronic devices are not recycled causing buildup of cadmium in the atmosphere by incineration or leaching into soil. Cadmium demand is a major player and a good measure of how much cadmium is in our atmosphere and how much will accumulate in the future. Unfortunately, cadmium demand has been increasing rapidly, “Apparent consumption of cadmium was 477 tons, a 140% increase from that of 2009. The annual average New York dealer price of cadmium metal in 2010 increased by 36% from that of 2009 to $3.90 per kilogram” (Tolcin 37). Cadmium consumption has increased substantially over a year, and consequently increased price. The reason for this increase lies in the nickel-cadmium (NiCd) battery market.

Since nickel-cadmium batteries have numerous applications in environmental renewable energy, demand for this product will increase, especially since there is no competitive substitute. NiCd batteries are used in various renewable energy technologies because of their long service life, low maintenance, and stability in harsh weather environments. NiCd batteries power electric vehicles in circulation and are also used as a power source in a limited number of hybrid electric vehicles. NiCd batteries were also used in transportable, renewable hybrid-power systems, developed to generate electricity in remote locations and underdeveloped regions (Tolcin 39).

Independent of cadmium demand, demand for other ores play a large part in cadmium exposure, as well. Since consumers and manufacturers constantly use zinc in their products, cadmium release as a byproduct is a large concern, "Regardless of cadmium demand…excess byproduct cadmium may need to be permanently stockpiled and managed, similar to the situation that the U.S. Government now faces with mercury" (Tolcin 39). If demand for ores that produce cadmium as a byproduct increases, cadmium will increase in the atmosphere and quickly accumulate in plants, animals, and ultimately humans. Amy Tolcin, a mineral commodity expert for the United States Geological Survey, even predicts the situation will be similar to the mercury crisis.

On one hand cadmium production and demand affect accumulation, on the other hand cadmium disposal also affects the toxin's presence in the atmosphere. 2.5 million tons of electronic waste were generated in 2007. 82% of e-waste is sent to landfills and incinerators. E-waste is projected to increase 3-5%. Landfills cause cadmium to leach into the soil. Burning the garbage causes cadmium to disperse in air. Environmentally friendly recycling is the only way to contain cadmium (Chen et al 431).

Cadmium toxicity is a deadly threat to children's dental, neurological and long-term health by affecting biological pathways involving calcium. Since the last public scare in 2010, little has been done to regulate cadmium, which is clearly increasing in the atmosphere due to the lack of recycling e-waste and increased demand for cadmium and zinc. Possible long-term sustainable solutions are phytoremidiation and containment chambers. Phytoremidiation, a cost effective green technology, uses organisms to ingest cadmium to remove the heavy metal from the soil (Song *et al*., 623). Cadmium can also be contained in chambers and recycled in factories to reduce employee exposure (OSHA 5). However, currently these technologies are very new and will take time to be embraced by industries. Despite its harmful effects, cadmium is also revolutionizing green technology. It is found in rechargeable nickel-cadmium batteries and as hybrid/electric power sources in cars and generators. People have the desire for the latest technology, and therefore they need cadmium batteries in their laptops, cell phones, and cars. Next, people need to ask themselves, do the technology benefits outweigh the health risks? When buying an electric car, a person reduces carbon emissions, but also increases cadmium emissions when that car is not recycled. Eventually, the government will need to regulate cadmium (Tolcin). Cadmium regulation will be a wake up call to finally get Americans to recycle their electronic waste and promote greener, healthier living.

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