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Current environmental mercury poisoning of children: A literature review of its impact on global pediatric health.

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Abstract

Mercury is a ubiquitous environmental pollutant with diverse adverse health effects that could result in death. Children are the most susceptible population of the world to mercury poisoning. Two earlier reviews by the author dealt with fatal mercury poisoning cases in the general population and mercury vapor exposure in dentistry. The objective of the present article is to review global studies on environmental mercury poisoning of children and get perspective on its impact on pediatric health by assessing the progress made in diagnosis, treatment, prevention and monitoring of the adverse effects. With the aid of several search platforms, studies of environmental mercury exposures in children published in the world literature were collected. With emphasis on clinical studies, details of the reported adverse health effects and treatments used were compiled along with prevention and monitoring aspects of mercury exposures. Mercury poisoning events were categorized based on exposure sites (at home or outside), its form (elemental, organic or inorganic), route (inhalation, oral ingestion, skin absorption or pre-and postnatal), duration (acute or chronic) and dose. The clinical signs, symptoms and treatments used in each category were separately enumerated for comparative purpose. Home is the most common site for children's exposure to mercury attributable to breakage of fever thermometers, dental amalgam fillings, tainted cosmetics, toys and jewelry, and consumption of contaminated fish, OTC and herbal medicines, and dietary supplements. The main organs affected are brain, lungs, kidneys and immune systems. Clinical interpretation of blood and urine levels of mercury are unambiguous when they are high and become difficult as they approach normal range. While diagnosing mercury poisoning can be challenging, it can be made with reasonable reliability and promptly treated with chelation therapy. With the development of mercury-free products and manufacturing processes along with industrial pollution abatement measures, children's exposure to mercury is currently being reduced. Parents, pediatricians, and school science teachers can play a major role in preventing mercury poisoning of children. This review should be of immediate interest to environmental scientists and regulators around the world.

Keywords: Mercury, Environment, Children's Health, Diagnosis, Prevention, Monitoring.

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Abbreviations: AA: Arachidonic Acid: AAP: American Academy Of Pediatrics; ADHD: Attention Deficit Hyperactivity Disorder; AHRQ: Agency For Healthcare Research And Quality (US); ASD: Autism Spectrum Disorders; ASGM: Artisanal and Small-Scale Gold Mining; ATSDR: Agency for Toxic Substances and Disease Registry (US); BAEP: Brainstem Auditory Evoked Potential; BASC: Behavior Assessment System for Children; BBB, Blood-Brain Barrier; BSID: Baby Scales of Infant Development; CDC: Center for Disease Control and Prevention (US); CHD: Coronary Heart Disease; CNS: Central Nervous System; CPT: Continuous Performance Test; DHA: Docosahexaenoic Acid; DMPS: 2,3-Dimercapto-1-ropanesulfonate; DMSA: Dimercaptosuccinic Acid; DNA: Deoxyribonucleic Acid; EFSA: European Food Safety Authority; EPA: Environmental Protection Agency (US); ER: Emergency Room; EU: European Union; FAO: Food And Agricultural Organization (WHO); FDA: Food And Drug Administration (US); FLB: Fluorescent Light Bulb; FTT, Finger-Tapping Test; GDS, Gesell Developmental Schedules; GI, Gastrointestinal; GMDS, Griffiths Mental Development Scales; HVAC: Heating, Ventilation and Air Conditioning; LED: Light Emitting Diode; MDI: Mental Developmental Index; MeHg: Methylmercury; MRI: Magnetic Resonance Imaging; MSCA, McCarthy Scales Of Children's Abilities; NHNE, National Health And Nutrition Examination (US); NIEHS, National Institute Of Environmental Health And Safety (US); NIH: National Institutes of Health (US); NIOSH: National Institute Of Occupational Safety And Health (US); NSA: National Science Foundation (US); OTC: Over-The-Counter; PDI: Psychomotor Developmental Index; PHS: Public Health Service US); PPVT: Peabody Picture Vocabulary Test; PUFAs; Polyunsaturated Saturated Fatty Acids; RFD: Reference Dose; RI: Risk Index; ROS: Reactive Oxygen Species; SACMEQ: Southern and Eastern African Consortium for Monitoring Educational Equality; SBIS: Stanford-Binet Intelligence Scale; Se: Selenium; SH: Sulfhydryl; TGMD: Test for Gross Motor Development; TMT: Trail Making Test; TWI: Tolerable Weekly Intake; UK: United Kingdom; UNFAO: United Nations Food and Agriculture Organization; US: United States (of America); VEP: Visual Evoked Potential; VER: Visual Evoked Response; VRM: Visual Recognition Memory; WHO: World Health Organization; WISC: Wechsler Intelligence Scale for Children and WRAVMA: Wide-Range Assessment of Visual Motor Abilities.

Introduction

Children are the most susceptible population of the world to environmental mercury poisoning. The two major routes of mercury exposure are inhalation of its vapor in the polluted air and consumption of fish and seafood contaminated with its organic form, MeHg. According to WHO [1], the ubiquitous and persistent nature of mercury and its compounds pose a threat for the healthy development of the world's children. The Minamata Convention [2] and EU Science for Environmental Policy [3] are currently addressing pediatric health problems raised by the complicated life cycle of mercury in the global environment. Study of early-life exposure to mercury and later-life diseases is a priority of the developmental origins of health and disease program of the US NIEHS [4] and WHO [5]. Also, WHO and the UN Environmental Programme have initiated global monitoring of children's exposure to mercury [6]. In recent years, notable progress has been made in curtailing exposure of children to this important environmental pollutant and monitoring the health of those exposed to it [7].

Mercury poisoning in the general population that resulted in death [8] and its vapor exposure in dental practice [9] were the subject of two earlier reviews by the author. The present review deals with pediatric mercury poisoning of children ≤ 18 yr. of age.

Historical perspective

Human exposure to mercury is due to its presence in the global environment from natural sources (69%) and continued human contributions (31%) from its industrial, commercial, medical and dental usages over the past 200+yr [10-19]. The earth's crust contains 0.05 mg mercury/kg and the current estimate of global mercury emissions is 7,527 Mg/yr. [20]. In the bioenvironment, mercury is transformed by microorganisms (plankton) to MeHg [21] and bioaccumulated in small fish feeding on it [22]. MeHg is further biomagnified in large predatory fish and other marine mammals ingesting these small fish [23]. Human contribution to the present-day mercury in Arctic marine animals used as food is estimated to be 92.4% [24]. The Arctic populations have blood mercury levels among the highest in the world that are associated with adverse health outcomes across life stages (from neurodevelopment in infancy to CHD in adults) [25]. The climate-induced amplification of MeHg in predator fish is projected to reach 8% by 2100 [26].

Mercury-containing industrial discharges (in addition to the atmosphere), agricultural runoffs (containing mercury-based fertilizers and pesticides) and domestic sewage (with mercury from cosmetics, OTC drugs, etc.) are the major polluters of lake, river and other large bodies of water [27-29]. Socioeconomic and health consequences of mercury pollution, and medical benefits of reducing mercury exposure in humans are current issues of global interest [30-33].

Mercury is devoid of any known physiological benefit and its exposure in any form (elemental, organic or inorganic) is considered potentially toxic to humans [34,35]. However, a physiological role for Hg++ during phototropic growth of the purple non-sulfur bacteria has been recently reported [36].

Based on an estimated ambient air level of 10 ng/m^3 mercury, its average daily intake in humans by inhalation is ~0.2 µg and from drinking water containing 0.5 µg mercury/L it is ~1 µg [37]. However, food is by far the largest contributor to human mercury exposure (2-20 µg/day) with fish and seafood being the major sources.

In the current global pandemic of corona virus disease 2019 caused by SARS-CoV-2 (COVID-19), reduction of mercury exposure may be considered as a potential tool for lowering vulnerability and severity of this deadly respiratory viral infection [38-41]. An unusual and paradoxical feature of the current COVID-19 pandemic is that children appear to be less severely affected by this virus than adults [42].

Children's exposure to mercury

The common forms and sources of mercury relevant to pediatric exposure are:

1. Elemental mercury, usually as vapor from mercury spills [43,44], dental fillings [45], religious practices [46] and tainted toys and jewelry [11],
2. Organic mercury compounds, MeHg being the most common through consumption of contaminated fish and seafood [47-49],
3. Maternal use of inorganic mercury compounds, such as bromide and chloride salts in cosmetics, household products, herbal medicines and dietary supplements [50,51].

The form of mercury a child is exposed to has significant effect on its toxic manifestation since there are major differences in the body uptake, transport and disposition of the three common forms of the metal [8,34,52]. Often children are simultaneously exposed to different forms of mercury which are generally chronic in nature and adverse effects tend to be definitive at higher doses but subjective at trace levels [1,18].

In children, vital organs (such as lung, brain and kidney, and immune systems) are at critical stages of development and often targets of adverse effects of mercury exposure [22,53-55]. This could occur even before birth since mercury readily passes through the placenta and enters the developing fetus during gestation in exposed pregnant women [56,57].

AAP has provided information on children's mercury exposure for practicing pediatricians [58] and the US EPA [59] has published guidelines to physicians in conducting mercury medical surveillance programs. Also, WHO guidance for identifying populations at risk from mercury exposure is available [60].

Alarmed by the reports of residual mercury vapor exposure of children in daycare centers and new condominiums which were converted from industrial buildings which used mercury and inadequately remediated, the US Congress in 2008 directed ATSDR and CDC to form the Mercury Workgroup to investigate such mercury exposure in children. In 2009, the Workgroup published a comprehensive report with the following conclusions [61]:

Children as a group are more sensitive to mercury vapor exposures in contaminated spaces and at higher risk than adult population. Since they breathe at a faster pace, have larger lung surface area relative to body mass than adults, and their shorter stature, crawling and play activities keep children's breathing zone closer to contaminated floor. The duration of such exposure (acute or chronic) and concentration of mercury govern the severity of adverse effects.

While environmental mercury poisoning of children around the globe continues to be reported to-date, there appears to be no literature review of the topic over a decade.

Literature Review

According to the 2020 annual report by the American Association of Poison Control Centers in the US, 1,965 calls pertaining to mercury were received with 1,256 involving broken fever thermometers [62]. Accidental mercury poisoning of children continues to be of public health concern in the US and around the world [63-71]. The objective of this review is to assess the current status of global mercury poisoning of children, provide up-to-date information on how to diagnose and treat, and appraise preventive and monitoring methods. This should be of interest to environmental scientists and regulators as well as pediatricians, medical personnel in hospital emergency rooms and poison control centers. Also, the information gathered should be useful to first responders and school science teachers in educating parents and their children how to minimize mercury exposure.

A literature search on the topic of mercury poisoning (key words: environment, mercury, poisoning and children) was performed using PubMed, MEDLINE, Academia-Edu, Science Direct and Google Scholar search platforms. Clinical studies published through June, 2023 were the main focus of this review. Those deemed relevant were used to collect detailed data on where, how, and the form (elemental, organic or inorganic) and nature (acute or chronic) of mercury exposures reported in children. Also, children's ages, biological samples used as biomarkers, clinical signs and symptoms of adverse effects, treatments and autopsy results (in the case of fatalities) were gathered. Available historical and chronological data on mercury poisoning were also compiled for possible extrapolation and its relevance to current events.

Results

Over 50,000 articles on the general topic of toxic effects of mercury exposures in children were available online. Of these, 534 were identified as relevant to this review objective and details of the reported exposure events were obtained. In general, the robust studies from Brazil, Canada, EU (primarily Scandinavia and Spain), UK and US were a salient part of this review. They were separated into various exposure categories based on different forms of mercury, common sites and sources of contaminations. Details of mercury concentrations in various biological and tissue samples used as biomarkers were collected. The reported clinical signs, symptoms and treatment of mercury poisoning was gathered under elemental, organic and inorganic forms of mercury.

In the US, EPA has recognized the following neurodevelopmental disorders in children attributable to environmental pollutants [72]: vision and hearing impairments, ADHD, learning and intellectual disabilities, ASD and cerebral palsy. Also, WHO recognizes the above disorders in evaluating health risk of environmental pollutants in exposed children [73].

From conception through adolescence, rapid growth and developmental processes occur in children which can be disrupted by exposure to mercury in the environment [1,22,53]. This occurs through: 1) maternal exposure, prenatally in the uterus and postnatally *via* breast milk, 2) inhalation, 3) oral ingestion and 4) skin contact.

Mercury affects the reproductive function of men as well as women [74]. During gestation, both elemental mercury and MeHg readily cross the placental barrier and accumulate in the fetus [75,76]. Mercury body burden of the mother is shared by her fetus and neonate which may result in larger exposure doses due to their lower body weights. Also, children consume more contaminated food and beverages for their body weight than adults. Overall, compared to adults, children have more years of future life and thus more time to develop chronic diseases that may take decades to manifest (lag time) after mercury exposure [76-80].

Inhaled elemental mercury vapor is readily absorbed in lungs (~80%) and crosses the BBB. In the brain, it is oxidized to inorganic mercury (Hg^{++}) and bound to macromolecules (DNA, enzymes, proteins, etc.) *via* SH groups. However, elemental mercury is slowly absorbed through skin and little is absorbed in the GI tract when ingested orally. In contrast, organic MeHg is readily absorbed through skin contact as well as in the GI tract (90%-95%) when ingested and crosses the BBB, biotransformed to Hg^{++} by demethylation and bound to macromolecules in the brain [81-84]. On a cellular level, MeHg induces oxidative stress by elevating ROS [85]. Since inorganic mercury compounds are poorly absorbed by dermal and oral routes (~10%), and do not cross the BBB, the main site for their accumulation is the kidney [55].

Inhaled elemental mercury vapor is excreted from the body in the exhaled breath, sweat and urine. Ingested mercury in liquid form is excreted in the feces unchanged [86,87]. Also, oral MeHg exposure leads to its excretion in the feces as inorganic mercury, since the gut flora can demethylate MeHg and modify its absorption and bioavailability [82]. The half-lives of the three common forms of mercury for elimination from the body are: elemental mercury (58 d), inorganic mercury (30-60 d) and MeHg (70-80 d) [83].

Elemental mercury generally does not accumulate in food [88] and MeHg usually not present in drinking water [36,89]. Diet and nutritional status of children (see Figure 1) have major impact on mercury toxicity [1,86,90,91].

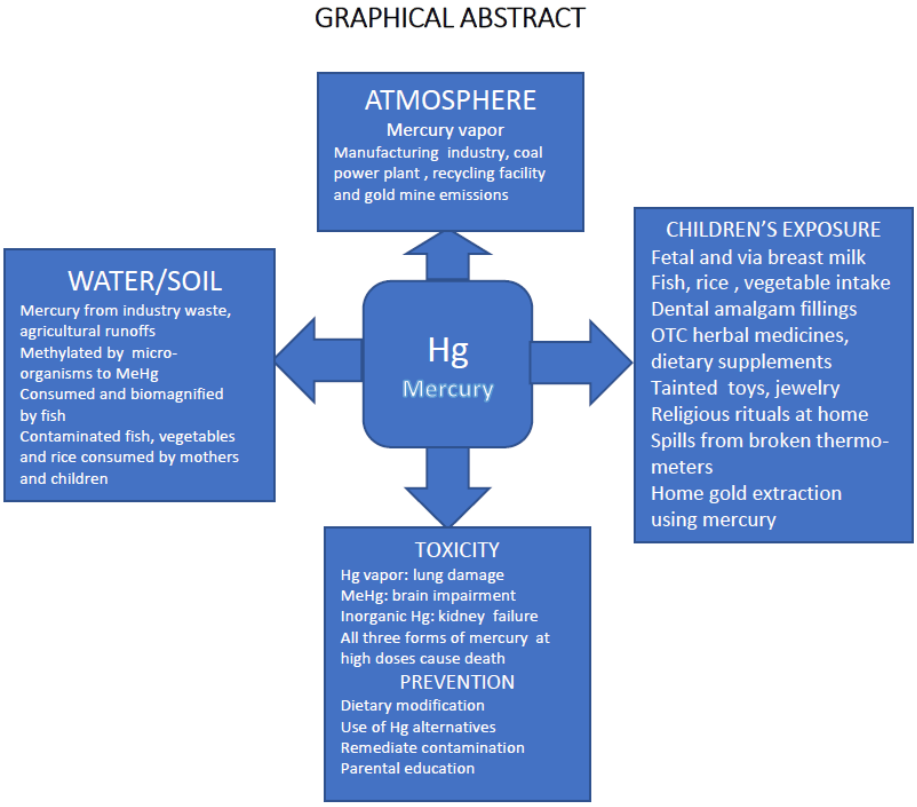

Figure 1. *Graphical abstract highlighting the origin of children's exposure to elemental mercury, its organic and inorganic compounds and modulatory effect of diet and nutrition on mercury toxicity.*

Discussion

The following are common sites for exposure of children to elemental mercury, and its organic and inorganic compounds:

Mercury exposure at homes

Home is the most common site for children's exposure to mercury. Such exposure occurs due to: 1) consumption of mercury contaminated fish and other dietary constituents, 2) breakage of mercury-containing devices, *e.g.,* fever thermometer, 3) heating mercury during unauthorized smelting operation by parents to extract gold and silver, 4) cultural or religious ceremonial utilization of mercury, 5) household use of unregulated cosmetics, herbal medicines and dietary supplements, and 6) family members unknowingly tracking mercury home from workplace. Additionally, children bringing home mercury from school science laboratories and abandoned factories could lead to the toxic metal vapor exposures (See below Sections From acute exposure to high doses of mercury and Mercury exposure at other locations, respectively).

From consumption of MeHg contaminated fish by mothers

Pregnant mothers who consume contaminated fish expose their offsprings to mercury during gestation and postnatally, through breastfeeding [48,49,92-94]. Mothers with lower body weight (<60 kg or ~132 lb) generally have higher mercury levels in their breast milk [95]. Extended breastfeeding (up to 3 yr.) is not significantly associated with elevated mercury level in children as measured in their scalp hair [96]. Interestingly, human breast milk contains mercury 8x WHO guideline amount for drinking water (1 µg/L), 4x that allowed in bottled water (2 µg/L), and higher than in dairy cow milk (<2 µg/L) [97] and infant formula milk powder (<0.5 µg/g) [98]. However, there is consensus that the benefits of breastmilk for infant outweigh any risk of mercury exposure [95,99-101].

The lactational exposure of infants to MeHg, a developmental neurotoxin [83,102,103], is reduced to ~50% at 2-3 mths of age compared to that expected on the basis of maternal blood levels [49,104]. During this early growth period, infant body weight gains rapidly (~1.5-2x) and the resulting increase in body volume appears to dilute MeHg levels (and lower toxicity) in breastfed infants.

While fish provide healthful dietary proteins and nutrients, such as omega-3 long-chain PUFAs (*e.g.,* DHA and AA) [92,105,106], these benefits may be offset by MeHg contaminant [107-109]. Fish contain 90%-95% of its total mercury as MeHg [110-112]. The EPA RfD for chronic MeHg exposure from diet is 0.7 µg/kg bw/wk (=mercury in blood, 5.8 µg/L and scalp hair,1.0 µg/g) for optimal health [113]. The provisional TWI of MeHg set by various regulatory agencies is 0.7-1.6 µg/kg bw [108,114]. However, in Japan where fish consumption is highest in the world, TWI for MeHg is 2.0 µg/kg bw [115] and its weekly average lactational exposure in infants is 0.63 µg/kg bw [116]. In 17 EU counties, mothers who consumed at least one fish meal/wk had hair mercury level ≤ 0.55 µg/g with about half of that in their children's hair [113]. In contrast, the Taiwanese infants have elevated mercury level (79 ng/g stool) at birth due to high maternal intake of mercury (>100 µg/mo.) from fish diet during pregnancy [117,118].

DHA and child development

DHA is considered a critical nutrient in the development of

nervous system and infant growth in the early life during gestation and while breastfed [76,105,119-126]. Both FDA and EPA recommend nursing, pregnant and childbearing-age women to consume twice a week seafood containing low MeHg and high DHA levels (*e.g.,* shrimp, pink salmon, seabass, mackerel, whiting, sole, pomfret and trout), and avoid those with low DHA and high MeHg (*e.g.,* whales, swordfish, shark, tuna, halibut, walleye, burbot and pike) [127-130]. Also, AAP, American Heart Association and American College of Cardiology recommend 200-300 mg DHA/day or 1-2 servings of fish/wk [131,132]. A Belgian study found such fish consumption to be safe for increasing the maternal DHA intake [133].

Worldwide human breast milk analysis found a wide range for DHA content (0.06%-1.40%) by wt.; optimal, 0.2-0.5%) with highest concentrations in seafood-consuming coastal populations [134]. Thus, breastfed children of mothers in Menorca, Spain with fish intake >2-3 times/wk during pregnancy (particularly during the third semester spurt of fetal brain development) and lactation achieved significantly higher MSCA scores when tested at age 4 yr. [135]. Additional studies also support such beneficial effects of breast milk DHA in children attributable to maternal fish consumption [136-138]. In the US, only ~25% of pregnant women consume the recommended quantity of fish needed to achieve DHA intake for optimal child health [139].

Since breastmilk DHA levels decrease during 12 wks postpartum, its supplementation is suggested for nursing mothers [140,141]. Thus, DHA supplement *via* maternal cod fish intake (twice a wk) has enhanced infant development [142-145]. Also, fish oil supplement has enhanced breastmilk DHA levels in nursing Australian women and development of their children (based on Griffiths score) [146]. Further, the long-range (at 2-4 yr.) developmental benefits of maternal DHA and fish oil supplements have been confirmed by an analysis of 34 clinical trials involving >16,000 breastfed infants [147]. Such supplementation is endorsed in EU [148] and Asia [149]. Nevertheless, studies in India [150], Italy [151] and Netherlands [152] have reported no such benefits of maternal DHA supplementation or fish consumption on child development in the short range (at 1-1.5 yr.).

Prenatal MeHg exposure

While moderate fish intake (1-3 times/wk; recommended by FDA and EPA) during pregnancy improves the metabolic health and inflammatory biomarkers in children, such intake >3 times/wk could lead to unfavorable metabolic profiles [153]. A study of the 14-yr.-old children in the Faroe Islands found an association between CPT (a measure of the speed of visual information processing) and high prenatal MeHg exposure from fish consumption during pregnancy (maternal hair mercury >10 µg/g) [154]. This was attributed to MeHg-induced dysfunction in the brain frontal lobes. Also, the survey of a large group of 44,824 Danish pregnant women with high consumption (60 g/day) of fatty fish (*e.g.,* salmon, trout and halibut) reported reduced fetal growth [155]. However, this study down played the role of MeHg and ascribed the results to other persistent organic pollutants in fish.

The Inuit children of high-fish consuming women in Arctic Quebec, Canada with cord blood mercury >7.5 µg/L were found to be 4x as likely to have IQ<80, the clinical cut-off score for borderline intellectual disability [156].

Interestingly, an analysis of MeHg in 130 placentas at birth in Kuopio University Hospital, Finland found higher amounts in primiparas (first time mothers) which increased with maternal age [76]. A study in Krakow, Poland found that the prenatal exposure to mercury (mean blood levels, maternal >0.5 µg/L and umbilical cord, 1.05 µg/L) from fish consumption, especially during the last trimester of pregnancy, delayed cognitive and psychomotor functions (using BSID scale) in 1-yr-old infants [157,158]. Other factors such as mother's age, country of origin, smoking and season of delivery were also significantly and independently associated with cord blood mercury concentrations [159]. An additional study found that smoking accelerated the loss of brain neurotrophic factor in newborn induced by maternal MeHg intake from whale diet [160].

In Mexico City, mercury levels in pregnant women (3.4 µg/L blood and 0.5 µg/g scalp hair) and children (1.8 µg/L blood and 0.6 µg/g scalp hair) have been reported [161] These mercury levels are 3-5x higher than those in the US and Canada primarily due to the consumption of seafood contaminated with mercury >EPA guidance value, 0.3 µg/g.

While prenatal mercury exposure is associated with greater risk of ADHD-related behaviors in children, fish consumption during pregnancy appears to provide protection against such behaviors [162-169]. There is ongoing discussion on the adverse effects of maternal mercury exposure on fertility, reproductive health and pregnancy outcomes [74,170]. Based on current evidence, dietary mercury exposure during pregnancy (blood range, 0.64-3.71 µg/L and hair levels, 0.3-5.7 µg/g) is unlikely to be a risk factor for neurodevelopmental deficits in early childhood (0-5 yr.) [171]. In this context, the potential study bias [1672] and difficulties in drawing definitive conclusions using neurophysiological tests in children exposed in utero to low levels of MeHg [173] are worth noting. (See Effect of dietary constituents... section below).

Genetics of prenatal MeHg exposure

The genetic predisposition of prenatal MeHg exposure on cognitive deficits (based on WISC-III) in 8-yr-old school children in Bristol, UK has been documented [174]. Also, a prospective study of 2-yr-old Taiwanese children suggested that variants of apoprotein E, a major protein transporter of mercury in the brain, may modify neurodevelopmental effects of MeHg [175]. Additional studies have confirmed that genetic factors can influence mercury toxicity [12,176-179]. Toxicogenomic is now being utilized as an analytical tool to detect mercury in seafood [180].

Prenatal MeHg exposure and heart disease

Regarding the question of whether prenatal MeHg exposure from fish consumption affects blood pressure in children, a study of 12 and 15 yr. old from the Seychelles Islands found no definitive correlation [181], However, similar 14 yr. study of the Faroe Islands birth cohorts observed decreased blood pressure attributable to MeHg neurotoxicity [182].

Several studies have concluded that MeHg from fish consumption may be a potential risk factor for CHD [22,183-186]. Such risk

increases when the hair mercury concentration reaches ≤ 2 μg/g [187]. Nevertheless, no association between mercury level and risk of CHD was observed based on toenail analysis in the US, EU and Israel [188,189].

Two recent meta-analysis of fish consumption data noted 60g fish/d as the ideal dose for preventing CHD mortality [190]. Further, higher consumption of fish (≥ 4x/wk) has been associated with greater protection against CHD [191]. The daily fish intake of 60 g happens to be the average consumed by the Japanese who are the highest fish consumers in the world. An earlier analysis of 8 studies of fish consumers (>once/wk) found 17% reduction in CHD [192].

From consumption of MeHg contaminated other dietary constituents by mothers

Among the other dietary constituents besides fish, a Swedish study of pregnant women found that consumption of chicken increased cord blood MeHg levels [193]. Apparently, mercury in chicken originated from fishmeal used as chicken feed.

In high-rice consuming countries, such as China, India and Indonesia, rice is an important dietary contributor of MeHg [45,194,195]. Methylation of mercury in paddy soil, sediments and water used to grow rice plant appears to be the source of MeHg in rice [196]. In China, rice may contain ≤ 569 μg of total mercury/kg, of which ≤ 145 μg/kg is MeHg [197]. The Chinese rice contains higher mercury levels than those grown in other Asian countries [198]. Rice seed has high accumulation potential for MeHg but not for inorganic mercury [199,200]. Notably, there is no significant difference in MeHg concentrations in brown and white (polished) rice since it accumulates primarily in the endosperm [201].

Thus, in inland China, rice rather than fish is the major source of MeHg exposure [202,203]. Stable mercury isotopes (^{199}Hg and ^{202}Hg) in scalp hair can be used to distinguish MeHg intake from rice *vs.* fish [204]. Compared to fish, rice has lower nutritional value and it lacks micronutrients, such as DHA and Se [205].

The recent survey of pregnant Chinese women found cord blood mercury levels (mean 2.26 μg/L) lower than the WHO/FAO recommended safe level (8.6 μg/L) [206]. Also, the latest rural Chinese child neurodevelopment study (based on BSID-II MDI and PDI) reported that contemporary changes in family structure had impacted children's sensitivity to maternal MeHg exposure [202].

Incidentally, the Chinese international rice trade has significantly aggravated MeHg exposures in Africa (62%), Central Asia (98%) and Europe (42%) [27]. Additionally, vegetables, such as cabbage, celery, spinach, pumpkin and amaranthus [207-210], and mushrooms [211] grown in mercury-contaminated soil and water have increased dietary mercury contribution (>FAO/WHO safe level). However, such mercury contamination can be mitigated by washing produce with water [212] or household vinegar [213].

From consumption of mercury contaminated fish and other dietary constituents by children

Ocean fish consumption is important for the health and development of children in many parts of the world [170,214]. The potential adverse effect of MeHg from contaminated fish consumption on children's IQ is being debated [156,215,216]. The amount of MeHg ingested depends on: 1) fish species, size, where and which season it was caught, 2) frequency of consumption, and 3) serving size (usually ~70 g/child) [129,130,217].

An advisory limit of 1 μg MeHg/g fish has been set by FDA [218]. The EPA threshold mercury dose for neurodevelopmental effects from fish consumption is 0.1 μg/kg bw/d [218]. Suggested weekly consumption quantities of DHA-rich fish (salmon, sardines, Atlantic mackerel, etc.) for children are: ages 5-11 yr. (average bw 14.4 kg), 40 g and ages 5-11 yr. (average bw 26.4 kg), 74 g with monthly limits for larger predatory fish (whales, shark, tuna, etc.) for 1-4 yr., 75 g and 5-11 yr., 125 g [219,220]. A recent survey of US children found blood mercury levels <EPA RfD (5.8 μg/L) in 1-19 old [58] with no adverse effect on adaptive and problem behaviors (based on BASC-2 scores) [221].

The desirable mercury level in scalp hair of fish-consuming children is <2.3 μg/g (WHO reference value) [222]. The form of fish consumed (fresh, frozen or canned) or how it is cooked (baked, grilled or pan/deep fried) generally does not affect its mercury content [223]. Since MeHg in fish has already bound to tissue proteins [73], it is not eliminated by cleaning or cooking [176]. However, acidic medium (*e.g.,* vinegar) can release mercury bound to fish proteins [224].

Based on VEP measurements in children, the Canadians have recommended the total blood mercury threshold limit of 8 μg/L for pregnant and childbearing-age women [225,226]. Among the Inuit population of Nunavik in Northern Quebec, staple diet of fish and marine mammals has resulted in higher mercury levels in blood and scalp hair of their children, the former correlating with neuromotor functions [227-229]. Similar results have also been reported in the Arctic populations [25].

EU has adopted the EPA RfD for MeHg exposure [230]. Studies of mother/child pairs in Ireland found scalp hair mercury levels<1.0 μg/g [231] and in the Italian coastal population of the Mediterranean Sea (which borders 21 countries), the MeHg levels from fish consumption were <TWI recommended by EFSA (1.3 μg/kg bw) [232]. In contrast, children in Spain (Granada, Madrid, Murcia, the Ribera d'Ebre and Menorca Island) have higher levels of MeHg in scalp hair [233-235]. Their consumption of oily and canned fish positively correlated with cognitive functions (based on MSCA scores) and negatively with white fish (bass, catfish, cod, tilapia, etc.) intake, especially when fried.

The biomonitoring studies of mercury in the Japanese children found no adverse effects on neurodevelopment (BAEP test) or scholastic achievement (SACMEQ test) attributable to fish consumption [79,236]. The reference level for mercury in scalp hair in Japan, the world's largest fish consumer, is 3 μg/g based on TWI of 2.0 μg mercury/kg bw from fish.

Although Jamaican children consume large amounts of seafood and their blood mercury levels are much higher (0.99 μg/L) than those in the US and Canadian children (0.33 and 0.31 μg/L, respectively), no association between blood mercury levels and ASD was observed [237]. This paper discusses discrepancies in

earlier studies that reported such association. A study with US children has also affirmed this conclusion [238].

The Chinese use fish congee as weening food for toddlers which may contain 50-520 µg mercury/kg depending on the type of fish used. This can result in the child's weekly intake of 1.2-13.0 µg mercury/kg bw. The infants fed such congee exceeding TWI of MeHg (1.6 µg/kg bw) have exhibited neurological and other symptoms of mercury poisoning [239]. Also, the fish-consuming Chinese children in Hong Kong have blood mercury level >5.82 µg/L with >9x higher risk of exhibiting ADHD [240].

In Australia, children's diet does not contain the recommended amounts of PUFAs, especially DHA since they consume 8.5x more meat than fish and seafood [241]. However, the high consumption of vegetables appears to help increase their total dietary PUFA intake [242,243]. Currently, infant formulas supplemented with DHA are popular in Australia [244]. The later-life benefits of DHA on neurodevelopment [245,246] and cardiovascular function [247] are the reasons for its supplementation.

The 2013 survey of 168 baby foods sold in the US found that 32% contained <0.146-4.060 µg/kg of total mercury with those containing rice topping the list [248]. Also, marlin fish jerky snack food popular with children in Hawaii and California contains high concentrations of mercury (average 5.53 µg/g) [249]. The recent US congressional report found up to 10 µg/kg mercury in some US made baby foods [250]. FDA has proposed a 4-yr. "Closer to Zero Action Plan" for baby food toxic metal contaminants which includes mercury [251].

Mercury-contaminated fish consumption pattern around the world

Like rest of the world, fish consumption in the US is the primary way the women of childbearing age and their children are exposed to MeHg, and it is generally below the level of any health concern [252]. Even so, according to the NHNE survey of 1999-2000, >300,00 newborns each yr. may have been exposed in utero to MeHg levels >EPA RfD [253]. Also, high fish consumption among women of reproductive age, especially African and Asian Americans, has resulted in preterm births in Maryland, South Carolina, Louisiana and Florida [254-258] with potential lower childhood IQ [156].

The 2008-2009 EPA survey of 541 sites across the continental US found mean mercury concentrations of 21-1,419 µg/kg fish [259]. The 2009-2012 survey of 5,656 US children ages 1-19 yr. found that 62.4% ate fish and had blood mercury levels below the EPA reference level, 5.8 µg/L [260]. An earlier survey of 1-5 yr. old children had also reported the historically lowest blood MeHg and total mercury concentrations (0.17 and 0.26 µg/L, respectively) [261]. However, the San Francisco Bay area children in California are known to be high-end fish consumers with elevated blood mercury levels [109]. Additionally, American children in Alaska and Hawaii have higher amounts of fish in their diet.

The fish consumption pattern in 17 EU countries has been studied [117]. The Portuguese are third largest fish consumers in the world, after Japan and Iceland. A survey of 343 pregnant women in Lisbon found their mean RI for MeHg exposure from fish consumption to be 0.81 (calculated by fish intake in µg/kg bw/d ÷ 0.24 µg/kg bw/d, the WHO tolerable daily intake; the desired RI <1.0) [262]. Notably, the ingestion of black and silver scabbard fish enhanced mercury toxicity risk.

The 2015 Spanish consensus document on the prevention of MeHg exposure has recommended that pregnant and nursing women as well as children should consume fish containing mercury levels <0.15 mg/kg, (resulting blood levels of ~10.8 µg MeHg/L and ~12 µg total mercury/L) [217]. This is comparable to the Japanese (who consume more fish per capita) but higher than those in the US, Canada and other EU countries.

The fish consumption of Finnish mothers appears to compensate the benefit and risk to child's brain development based on IQ measurement [76]. Also, among the Finnish fishermen families whose intake of contaminated fish is high (64-89 g/d, 2x general population), no adverse effect on mortality is observed [263].

In South America, an analysis of 110 species of fish from Madeira River, the biggest tributary of Amazon in Brazil found a concentration range of 0.01-6.06 µg mercury/g [264]. Among the high fish-eating villagers (~406 g/d), mean scalp hair-mercury level (17.4 µg/g) of breastfeeding mothers significantly correlated with their children's hair level [265,266]. While this had no significant impact on newborn birthweight [267], impairment in motor performance (TGMD-2 test) was observed at ages 7-11 yrs. [268]. However, such developmental delays were also attributable to their health inequalities and socioeconomic disadvantages [96].

The children with fish as the main component of their diet (283 g/day containing ≤ 0.2 µg mercury/g) in the fishing communities along the Caribbean coast of Colombia are potentially exposed to MeHg 3x WHO/FAO TWI, 1.6 µg/kg bw [269]. Similarly, the children living in the northern border area are exposed to high levels of MeHg from consumption of fish from rivers polluted by mercury-containing wastewater from the artisanal gold mines [270].

West Bengal is a high fish consuming state in India with a population of >10 million children of age ≤ 6 yr. The 2016 analysis of scalp hair of younger residents (<21 yr.) of a fishing community near Kolkata, the state capital found mean total mercury value less than EPA RfD (1.0 µg/g) [271]. The city residents had lower hair mercury level (0.49 µg/g) compared to those from the fishing community (0.83 µg/g), presumably due to lower fish consumption. Also, recent surveys of commercial fish from the Bay of Bengal [272], coastal Mumbai [273] and Goa, another high fish consuming region [274], found mercury levels within the permissible limits.

Over the past five decades (1961-2011), there has been a world-wide increase in human exposure to MeHg from fish consumption (>TWI 1.6 µg/kg bw) [275]. The annual health benefits of a 10% reduction in MeHg exposure in the fish-consuming US population is estimated to be $860 million [276]. Of this, 80% is associated with reduction in fatal heart attacks and 20% in IQ gains in children. EFSA [277] has recommended that each country needs to consider its own pattern of fish consumption for risk-benefit analysis. Sushi fans should note that raw fish may contain 55%-60% more bioaccessible mercury than in cooked or fried ones [278,279].

Reports of biomonitoring and risk assessment of mercury contamination in fish from various parts of the world are available [280-282]. Also, there is a compilation of mercury content of vegetables, fruits and fish consumed in India which, in general, is within TWI [283].

A field experiment in France found that risk-benefit advisory had minimal effect on consumer fish choice [284]. Instead, store warning labels on fish with high mercury content were recommended as a more effective tool. In the US, consumer advisories also have no major impact on fish choices made by the women of childbearing age [285-287].

Thus, both maternal and children's consumption of mercury contaminated fish and other dietary constituents continue to be of active research interest around the world.

Mercury vapor exposure from mercury-containing devices

Mercury is the only element that is liquid at room temperature, 13.6x heavier than water and readily evaporates. One 4-mm diameter bead of mercury (0.034 ml or 0.46 g) can generate at 0.1 m above ground, up to 0.56 μg mercury vapor/m^3 of room air in 30 min at 170°C. This vaporization increases rapidly as temperature rises, *e.g.,* ~6x at 38°C [288].

Since mercury vapor is colorless and odorless, its detection in home could be challenging without professional help. If concentrations >1 μg mercury/m^3 room air are detected, cleanup should be initiated and residents evaluated for exposure [289]. Their relocation is called for when the mercury reaches toxic level of ≥ 10 μg/m^3 room air [290-292].

The most common cause of mercury vapor exposure of children at home is due to broken fever thermometers, blood pressure monitors and light bulbs. Although spills from broken thermometers (which contain 0.5-0.7 g mercury) rarely reach mercury vapor levels >1 μg/m^3 room air [43,64,292]. they could create hazardous conditions to infants if such indoor spills are improperly cleaned (See Clinical signs, etc. section below). In contrast, blood pressure monitors contain larger amount of mercury (~150 g) and when broken, they are more likely to create a hazardous situation, as in the case of a home day care center in Hillsborough County, Florida. Unknowingly it utilized a leaking antique monitor (resulting in ≤ 89 μg mercury/m^3 room air) as an educational toy [293]. Also, a recent mercury spill entered HVAC system in the basement of a house in Virginia exposing a family with 3 children to toxic vapors [294].

Since spilled mercury disperses into small droplets that get embedded in carpet fibers and floor cracks, vacuum cleaning produces aerosols and enhances its vaporization. Thus, the recent attempt to vacuum clean a spill of ~40 g of mercury from a broken barometer in a Netherland home resulted in high blood levels (26-32 μg/L) in a boy (9 mos.) and his sister (2.5 yrs.) within 6 h of exposure [295]. Similar poisoning of children in the US attributed to vacuum cleaning of mercury spills from broken thermometers has been reported [67]. Hence, vacuuming or using broom to clean mercury spill is not recommended [289]. Poor ventilation and elevated temperatures further increase mercury levels in the room air. Activated alumina may be used to cover-up inaccessible mercury spillage to reduce vaporization [9]. Mercury spills larger than that from a broken thermometer need to be promptly remediated by professionals [296,297]. A review of health consequences of mercury spills from common devices at home is available [44]. Most countries have mercury emergency phone hot lines. In the US, it is 800-220-1222 at the Poison Control Center.

ln contrast, the widely-used 4-ft long fluorescent tube lights contain smaller amounts of elemental mercury vapor (12-20 mg) and only 6% of this is released to the air when broken. Notably, mercury binds to glass as the bulb ages and ~4 mg is oxidized [298]. The compact FLBs contain even smaller amounts of mercury vapor (3.0-4.5 mg). Thus, mercury hazard from broken light bulbs in homes is minimal. In most instances, the small amount of mercury released can be adequately vented by opening windows and using exhaust fans to achieve the EPA reference level (≤ 0.3 μg/m^3) [289].

In the rare instances of broken fever thermometers in the mouth of young children, as recently reported in Shanghai, China, X-ray images can help locate mercury residue and in one child, local excision was resorted to remove it from the floor of mouth [299]. Accidental ingestion of mercury from a broken thermometer is generally non-hazardous due to its poor absorption in the oral cavity and GI tract [8]. There is a recent report of mercury in the vomitus after drinking milk spiked with the metal [300]. Similarly, absorption of elemental mercury through skin contact is low (0.024 ng/m^2 for each mg/m^3 room air) [61].

Exposure from heating mercury to extract gold and silver from ores and scrap

Extraction of gold and silver from ores by mercury amalgamation and from scrap dental fillings involves heating which could generate potentially lethal concentrations of vaporized mercury (0.193-0.370 mg/m^3 room air). Such operations at home by amateurs, especially in the poorly ventilated residential kitchens have resulted in children's death [301,302]. Also, fetal uptake of mercury could take place in exposed pregnant women due to its facile transfer across the placenta [303]. (See Clinical signs, etc. section below).

To avid entrepreneurs, there is good news of the availability of a mercury-free gold extraction procedure which uses Borax (sodium borate), a common ingredient of household cleaners and laundry detergents [304].

Exposure from cultural or religious ceremonial uses of mercury

Some Caribbean and Latin American religions, such as Voodoo, Santeria, Palo and Espiritismo use mercury ceremonially and apply it to the skin, add to candles or sprinkle around the house [46,55,303,305]. As a precaution, homes of these religious practitioners should be monitored to assure mercury levels are <1.0 μg/m^3 room air. Also, blood, urine and scalp hair levels of mercury should be checked in young children suspected of such ritualistic exposures [306].

Exposure from unregulated cosmetics, herbal medicines, dietary supplements, toys and jewelry

Chloride and bromide salts of mercury are commonly used in cosmetics, herbal medicines and dietary supplements [307].

The 2003 FDA list of mercury containing medicinal products is still of current relevance due to their continued popularity [308]. Also, low-cost jewelry and toys from Mexico and Asian countries are often contaminated with mercury [309-311].

Parents and other family members use of facial skin-lightening creams containing mercury salts (which inhibit melanin formation) may expose children to the toxic metal [66,312-316]. Also, mercurous chloride (calomel) in teething powder is known to cause childhood mercury poisoning (acrodynia or pink disease, see Clinical signs, etc. section below).

Herbal medications sold OTC in pharmacies and *via* the internet are often contaminated with mercury (some as high as 103 mg/g). Also, mercury concentrations >4.2 mg/g in herbal dietary supplements are not uncommon, with bamboo shoots and green microalga being the frequent contributing ingredients [317,318]. However, mercury in traditional Ayurvedic medicinal products from India is generally not a contaminant but added as an active ingredient [319]. Mercury poisoning of children in the US and EU by such medications has been reported [320].

Moreover, herbal teas could be a significant source of mercury exposure in children [321]. (AAP recommends not to feed infants herbal teas (which may also contain other toxins, such as pennyroyal oil in mint tea) which could lead to fatalities [322].

In the US, FDA (per 21CFR700.13) has approved the use of mercury compounds as preservative in eye products only (at ≤ 65 μg/g) [308]. Thus, all cosmetics containing mercury >1 μg/g. with the exception of eye products, are considered contaminated and subject to regulatory action.

Exposure from workplace tracking of mercury to homes

Elevated levels of mercury in children and homes of workers of plants manufacturing thermometer, FLB and chlor-alkali products have been reported [299,323,324]. Thus, in the US, the urine mercury level was higher (25 μg/L) in the children of a Vermont thermometer plant workers than those of non-mercury plant workers (5 μg/L) [324]. Also, mercury contamination in homes of a chlor-alkali plant workers in Charleston, Tennessee during scheduled maintenance has been reported [323]. Although no toxic effects were observed in both cases, the children of mercury plant workers are potentially at risk and monitoring is advised. Additionally, it is prudent for the plant workers to wear separate work clothes and shoes to prevent carrying mercury contamination outside of the work area [9].

Workplace tracking of mercury from clinic to home by dental professionals who work with mercury containing amalgam fillings is considered not significant because of the relatively small quantities of the metal they handle. (See Exposure to mercury used in dentistry section below).

A recent indoor air mercury monitoring in ten hospitals in Bali, Indonesia found that 90% of the hospital area had <1 μg/m^3, 9% 1-10 μg/m^3 and 1% >10 μg/m^3 with higher concentrations in emergency rooms and dental clinics, and the highest in equipment repair/maintenance workshops [325].

Exposure from industries that use mercury near homes

Chlor-alkali plants produce chlorine, hydrochloric acid, caustic soda (sodium hydroxide) etc., using mercury cells each containing about 8,000 lb of mercury. A typical plant uses about 56 such cells [326]. Elevated levels of MeHg in water (7 ng/L) and fish (5.2 mg/kg) in a Romanian reservoir due to microbial methylation of mercury released from a chlor-alkali plant have been documented [327]. Similarly, leafy vegetables grown near a chlor-alkali plant in Ganjam, Odisha State, India contained elevated mercury levels (8.9 mg/kg) [328]. Also, higher atmospheric levels of mercury (27.4 μg/m^3 air) in the vicinity of chlor-alkali plant in Flix, Spain are reported [329]. The scalp hair MeHg analysis of 4-yr. old children living near this plant found twice the amount (0.631 μg/g) compared to those not living near the plant [330]. However, their hair mercury levels decreased over the 13-yr. period with no correlation with neurophysiological test scores (TMT-B and FTT) and ADHD [331]. Similar results were obtained in the vicinity of a chlor-alkali plant in Portugal shut down after 50 yr. of operation [332]. Further, a detailed study of ambient air, soil and vegetables grown in the vicinity of a chlor-alkali plant in Tuscany, Italy found mercury concentrations within the EU safe level [333].

In 2014, there were an estimated 50 chlor-alkali plants around the world and in the US, just 2 as of 2018 [334]. The environmental exposure hazards to children are minimal from other industries that use smaller quantities of mercury (*e.g.,* thermometer and FLB manufacturers). An exception was a US-owned thermometer factory in Kodaikanal, Tamil Nadu, India. It was shut down for blatantly polluting the pristine environment of the popular hill station by discharging waste mercury in the early 2000s [335].

Mercury exposure at schools

Students are attracted to silvery liquid mercury which disperses into tiny droplets and quickly forms large globs upon shaking or scooping with fingers [336]. The common sources of mercury vapor exposure at school are: 1) elemental mercury stored in science laboratories, 2) mercury from broken instruments and FLBs, and 3) gymnasium floors covered with certain polyurethane material (such as 3M Tartan) manufactured prior to 1985 using mercury-containing catalyst [61,310].

Student misuse of mercury accounts for numerous short-term exposures to its vapor as reported in Arizona, Mississippi, Missouri, Nevada, Texas and Washington, DC schools in the US [68,337-339]. Thus, mercury stolen from storage rooms was taken to class rooms, gym and homes. The air mercury levels measured were highest near the student locker rooms (50 μg/m^3 compared to the background, 0.01-0.04 μg/m^3). The mean urine mercury level of 200 students tested was 0.36 μg/L (range 0.14-11.4 μg/L) with higher levels in those touched mercury and/or got it on their clothes. One school was closed for 35 days for cleanup and over 200 homes were tested for contamination. In the most recent incident, a high school in Chicago, Illinois was evacuated after the discovery of mercury in bathroom toilet (Chicago Tribune, Jan 14, 2023).

In general, there have been not many reports of severe adverse effects in students that required medical attention due to mercury exposures in the US schools [337]. In 2020, three students in Dallas, Texas developed symptomatic elemental mercury poisoning that required hospitalization and chelation therapy with DMSA [68].

Besides the US, in the past 10 yrs. many students in Turkey were poisoned by mercury in several schools [69,340-342]. Over 250 children were exposed by unauthorized handling of mercury and in one case, 26 were intoxicated as the result of a broken mercury thermometer in a hot, closed-door laboratory. These acute mercury vapor exposures were detected early on and successfully treated with D-penicillamine or N-acetyl cysteine.

A mercury awareness guide for school teachers is available [343]. The acceptable level of mercury in indoor air for school is 1-3 μg/m^3 which is higher than that for home (<1 μg/m^3) accounting for less time spent in school by children [344].

Mercury exposure at other locations

In the US, children's exposures to mercury vapor at other locations, such as repurposed daycare facility at a former mercury thermometer factory [345] and residential condominium conversion of a building that used to manufacture mercury vapor-containing light bulbs, both in New Jersey, have resulted in enhanced urine mercury levels due to inadequate remediation [346].

Also, there are reports of children's exposure to mercury discarded on abandoned industrial properties. Thus, two teenagers scavenged a large amount of mercury (~23-100 lb) from a shuttered neon sign factory in Texarkana, Arkansas and contaminated 12 residences, 1 convenience store, and a local school [347]. One home and an apartment were so severely contaminated that both had to be demolished. Although exposed children had high mercury levels in urine (66.6 μg/g creatinine) and blood (104 μg/L), no lasting adverse effects were reported because of prompt intervention.

Similar incident of youngsters hoarding large quantities of mercury (~220 lb which needed a wheelbarrow to haul) from a railway tilt switch facility in Manchester, UK has led to exposure of 225 juveniles [348]. Many were at high risk and needed chelation therapy with DMPS. Also, in 1993, children in Hamilton, Canada took mercury from an abandoned metal recycling plant and distributed to their peers creating a major mercury emergency [349]. This resulted in screening of ~6,000 children, and 269 were identified as exposed to mercury. Fortunately, none of the exposed children exhibited adverse health effects thanks to quick action taken by the local public health officials.

Other examples of innocuous mercury vapor exposure events include mercury poisoning of a 24-mo.-old toddler in Syracuse, New York whose case of acrodynia (peeling pink skin at the tips of fingers and toes) was due to mercury vapor from broken FLBs stored in a shed next to his nursery [350] and mishandling of the mercury spillage from a broken blood pressure monitor in the waiting room of a clinic in Detroit, Michigan [351]. In the latter case, no child was harmed thanks to the prompt response by the alert staff.

Mercury exposure from other sources

The US EPA [334] list of the major contributors to mercury pollution of the air includes: Chlor-alkali plants, coal burning power plants, waste disposal and landfill sites, auto crushing yards (mercury from antilock brakes), recycling facilities for FLBs, thermometers, switches and gears, human crematoriums (mercury released from dental amalgam fillings) and mobile sources (locomotives and marine vessels). It is noteworthy that adverse pregnancy outcomes in communities near incinerators and crematoriums have been reported [352].

The sobering finding of 80% reduction in atmospheric mercury pollution from 1990 to 2014 (~250 to ~50 tons) [334] is attributed to both reduced mercury usage due to the development of mercury-free new technologies and implementation of better pollution control measures. Reviews of recent abatement innovations in industrial mercury pollution are available [353,354].

The total amount of mercury released to environment from global coal combustion is estimated to be 38 Gg (~71% atmosphere, ~31% land and water) [355]. Most of it is released in Asia and Europe (32% each). A 2005 analysis in the US concluded that unilateral reduction of mercury emissions from coal-fired power plants alone is unlikely to realize any significant public health benefits [356]. Less than 2% of the total mercury emitted from 3 coal-fired US plants was detected within 15 km (9.3 miles) of the plants with low health risks attributable to such emissions [357,358]. While soil mercury levels were low and considered safe, there is concern for exposure risk to toddlers playing out doors due to potential oral contact [359].

Interestingly, lower tissue mercury and higher Se concentrations were found in fish from lakes near power plants [360]. Also, a survey of 2-yr.-old Chinese toddlers with prenatal exposure to mercury in coal-burning plant pollutants found no development defects based on GDS [361]. However, a recent study has reported higher mercury levels (>WHO TWI) in grain and vegetables grown near coal-burning power plants [212].

The cement industry in India is the second largest in the world (next to China) and emits 45.6 mg mercury/Mg cement produced. This is substantially less than the EPA reference level of 65 mg mercury/Mg [362]. While the limestone raw materials used are the source of such contamination, both India and China have yet to set mercury emission standard for cement plants [363]. Studies have shown that cement plants located in urban areas can increase health risk of children. Thus, a survey of school children in Barletta, Italy found elevated toenail mercury level (0.15 μg/g *vs.* 0.09 μg/g in control group) attributable to a nearby cement plant emission [364].

Following the unprecedented terrorist attack on World Trade Center in New York City by crashing two highjacked passenger planes into its 110-story twin towers on September 11, 2001, large amount of mercury (from thousands of gallons of burning jet fuel and gasoline from parked automobiles, their exploding antilock brakes and FLBs in the two towers) was released into the air. While blood mercury (2.29 μg/L) was not significantly raised in pregnant women living or working near the crash site, higher cord blood mercury (5.0 μg/L) was associated with reductions in developmental scores (MDI and PDI) in their children [365].

Historically, amalgamation with mercury has been used for more than 4,500 years in mining precious metals [366]. A literature review and bibliometric analysis of the current use of mercury in gold mining is available [367]. About 37% of mercury emitted to global environment is produced by ASGM

regions located in some 19 countries in South America, Africa and Asia [368]. The scalp hair and urine mercury concentrations of children in these gold mining regions are>WHO guidance value and correlate with lower neurophysiological test scores (SBIS and WISC-III), and kidney and immune dysfunctions [368-372]. But such mercury exposure has decreased in recent years due to diminished mining activity as alluvial deposits got depleted [373]. However, in some ASGM regions children continue to be exposed to higher levels of mercury [10] exacerbated by consumption of heavily contaminated fish, *e.g.,* Peru, Senegal, French Guiana and Ivory Coast [111,366-377]. (See Simultaneous exposure…. section below). Also, Mexican children are exposed to higher levels of environmental mercury pollutant from industries performing primary and secondary extraction of gold and silver [378].

Among the current productive cinnabar (mercuric sulfide, the most common mercury ore) mining regions, the following scalp hair mercury levels in children are reported: 1.4 μg/g in Wanshan, Guizhou, the largest in China [379] and 2.64 μg/g in Almaden, Spain, the site of one of the world's oldest and largest mercury deposits [380].

Exposure to mercury used in dentistry

Ancient Egyptians were known to use a mercury amalgam to fill tooth cavity over 1,500 years ago [35]. First documented in a Tang Dynasty Chinese medical text by Su Gong in 659, the widespread use of mercury-based dental amalgam is attributed to the invention of the English chemist Charles Bell in 1819 [381]. A typical dental amalgam contains 50% mercury, 30% silver and the remaining 20% copper, tin and zinc. Worldwide it is estimated that 100 tons of dental amalgam mercury enters the waste stream annually [13].

The three potential sources of children's exposure to mercury from dental amalgam are: 1) occupational exposure of their parents in dental profession, 2) systemic pre-and postnatal release of mercury from dental amalgam fillings in mothers, and 3) mercury released from dental fillings in children themselves.

From exposure of parents in dental profession

In the dental office, dentists and their staff are exposed to mercury vapor while filling tooth cavities with mercury-based amalgams [13] and during sterilization of amalgam-contaminated instruments [382]. Potentially harmful urinary mercury levels (20-50 μg/L) in the dental personnel were common during 1960-1970's [9,383]. The modern dental practice complies with NIOSH safe mercury exposure level (≤ 0.05 mg/m^3 clinic air). This has been affirmed by the 35-yr. (1974-2009) mercury monitoring of dental clinics [384]. Further, recent studies of pregnancy outcomes among dental professionals found no increased occurrence of birth defects attributable to prenatal occupational exposure to mercury [385,386].

From release of mercury from dental amalgam fillings in mothers

At body temperature of 370°C, the average amount of mercury vapor emitted in the mouth from the surface of dental amalgam filling is 1.2 μg/cm^2/d, and its systemic uptake and urinary excretion are well-documented [9,61,387]. In the mouth, mercury is methylated to form MeHg by the oral bacteria and accounts for its non-dietary source in the body [388]. For every 10 amalgams placed in the mouth, the urinary mercury level increases by 1 μg/L [389].

Mercury released from maternal dental amalgam fillings passes on to fetus and breast milk, but unlike MeHg from fish, there is no definitive evidence for its adverse health effects [55,390-392]. A survey of Brazilian nursing mothers found no correlation between breast-milk mercury and dental amalgam fillings [393]. Also, the Norwegian mother/child cohort study of children born in 1999-2008 found no unequivocal correlation between number of dental amalgam fillings and perinatal death [394].

From release of mercury from dental amalgam fillings in children

Like adults, children are also susceptible to mercury vapor exposure from dental amalgam fillings [395]. As with adults, there are no reports of adverse health effects of such mercury exposure in children [396,397]. Thus, a study of Portuguese children in Lisbon found no behavioral effects of mercury amalgam fillings when compared with mercury-free composite resins used to fill dental cavities [398]. Also, the children in 17 EU countries showed no significant contribution to scalp hair mercury level from dental amalgams [117]. However, the number of amalgam fillings had a significant dose-response relationship with urine mercury levels which increased with gum chewing [399].

The FDA White Paper has concluded that both maternal and children's dental fillings pose no health risk to children [45]. It noted that neurologic and organ-specific effects appear when mercury vapor levels reach >50-100 μg/m^3 air or >50-100 μg/g of creatinine in urine. The best estimates of mercury exposure in children from all sources are substantially less than these reference toxic levels [400]. A recent study of Spanish children found that mercury neurotoxicity is not associated with ASD [401]. However, the topic of mercury exposure and ASD continues to be of active interest [41,402-404].

The American Dental Association has recently updated its longstanding affirmative position on dental amalgam safety with the statement: Although amalgam remains an effective and inexpensive restoration option, environmental concerns regarding mercury have fueled legislative and regulatory actions in other countries to phase down amalgam use [405]. Denmark, Norway and Sweden have banned the use of mercury amalgam fillings and its use is severely restricted in Japan [406]. Also, as of 2018, UK and EU no longer allow mercury amalgam use in children under the age of 15 yr. and a recommendation for its complete phase-out by 2030 is being considered [407]. Further, Germany and Canada advise against its use in children and pregnant women [408].

There is encouraging news for parents concerned about the safety of dental amalgam containing mercury. Silver diamine fluoride appears to be a viable alternative to mercury amalgam for filling cavities in children which requires no anesthesia or drilling [409]. Although this mercury-free restorative compound has shorter durability (~5 yr. compared to 15-20 yr. for mercury amalgam), it is suitable for filling deciduous teeth cavities in children.

Simultaneous exposure of children to multiple forms of mercury

Children are simultaneously exposed to multiple forms of mercury: 1) elemental mercury vapor in the environment, contaminated home and from dental amalgam, 2) MeHg from breast milk, fish and seafood, 3) ethylmercury from vaccines, and 4) inorganic mercury from family use of unregulated cosmetics, dietary supplements and herbal medicines.

A Swedish longitudinal study found distinct levels of intoxication for each mercury species (metallic, inorganic and organic) with dominant contributions from maternal MeHg from fish diet and elemental mercury from dental amalgam fillings [410]. The serum and scalp hair mercury levels depend on the type of fish consumed, Se content in the diet, the number of amalgam fillings and where the children reside [411,412].

The New Hampshire Birth Cohort Study using maternal toenail analysis found that gestational mercury exposure from seafood consumption and dental amalgams was associated with increased risk of lower respiratory infections in infants [110]. However, the British Avon longitudinal study found that such prenatal exposures, in addition to ambient air mercury were not adversely associated with offspring IQ (WISC-III) [413]. Also, the atmospheric mercury exposure of Chinese children from fossil fuel combustion coupled with MeHg intake from rice and fish diet generally resulted in low cord blood [414] and scalp hair mercury levels [190,194,207,415].

In contrast, a comprehensive review of 72 studies of children living in 19 South American, African and Asian ASGM communities exposed to mercury in the environment and MeHg from fish diet found: 1) high mercury concentrations in their scalp hair (>2.3 µg/g) and urine (up to 667 µg/g creatinine) [368] and 2) they were susceptible to kidney and neurologic toxicities [1]. (See Mercury exposure from other sources section above). An additional source of mercury exposure is ethylmercury-based preservative used in children's vaccines [308]. Consequently, children in such ASGM communities continue to be exposed to higher levels of mercury [10,375]. While several epidemiological studies have found no conclusive evidence for neurophysiological or kidney toxicities attributable to such mercury exposures in infants and young children [55,416,417], the clinical manifestations may be delayed due to the latency period [78,80,418,419] and follow-up studies are warranted.

Thus, when evaluating mercury poisoning of children, simultaneous exposures to its different forms from all sources need to be considered.

Clinical signs, symptoms and treatment of mercury poisoning of children

The medical journals around the world are replete with articles describing the clinical signs and symptoms of mercury poisoning in children. Chelation therapy appears to be the most frequently used treatment for mercury poisoning.

General toxic effects

Environmental mercury exposure affects anatomical, physiological, metabolic and functional processes in children involving CNS (brain and spinal cord), lungs, kidneys, liver, eyes, ears, skin, and digestive and immune systems [1,15,22,56,65,419]. The symptoms and severity of mercury toxicity vary with its form (elemental, organic or inorganic), exposure mode (acute or chronic), route (inhalation, oral ingestion or skin absorption) and dose. For example, effects of different forms of mercury on eyes are: 1) elemental mercury vapor causes inflammation of cornea (keratitis by calcium deposition), 2) organic mercury impairs hearing (by damaging auditory hair cells) and vision (by constricting visual fields and degrading VER), and 3) inorganic mercury damages corneal endothelium (by changing opacity) and lens (by brown discoloration known as mercurialentis, a trademark early sign of mercury poisoning) [342,420].

Organic mercury compounds cause CNS, neurological and behavioral adverse effects similar to elemental mercury vapor exposure, *e.g.,* seizures, bronchitis, pneumonia, loss of motor and cognitive skills [49,103,342,421-424]. Other toxic signs of mercury vapor inhalation common with skin contact with its inorganic salts are: irritability, stomatitis (inflammation of oral mucous membranes), erythema (abnormal redness of hand, feet and other body parts), acrodynia, and erethism (behavioral and personality changes, extreme shyness, excitability, loss of memory and insomnia). Oral ingestion of inorganic mercury compounds causes GI distress and kidney damage.

The most frequently reported non-neurologic adverse effects of mercury and its compounds in children are contact dermatitis and cutaneous poisoning [8,34,425]. The hematological effects (anemia, lymphopenia, etc.) of mercury exposure appear to be rare in children [426].

Since mercury is in ionic form (Hg^{+} or Hg^{++}) in its salts, they are readily absorbed in the body. In contrast, elemental mercury is slowly absorbed due to its nonionic form (Hg^{o}) [8,427]. Thus, orally ingested liquid mercury passes in the feces unchanged with little absorption or discernable toxic effect.

In general, among the three forms of mercury, chronic exposure to organic mercury compounds is more toxic to children than its metallic or inorganic forms. Conversely, acute exposures to mercury vapor and its inorganic salts are more toxic to children than organic mercury compounds. However, all three forms can be fatal in high doses. The major differences between organic and inorganic mercury poisoning are: MeHg causes brain damage, while mercury vapor damages lungs and mercury salts impair kidneys. The pathological differences in poisoning due to the three forms of mercury are well documented [426].

The potential toxic effects of maternal mercury exposure in children are: 1) prenatally: miscarriage and stillbirth, 2) at birth: low body weight, congenital malformations, vision and hearing deficiencies, and cognitive dysfunctions, 3) at infancy and childhood: higher mortality, asthma, neurobehavioral and immune impairments, 4) at adolescence: precocious or delayed puberty, and 5) at adulthood: increased risk of cancer and heart diseases [74].

Biomarkers and biomonitoring of mercury exposure

The frequently used biological specimens as biomarkers of mercury exposure in children are: blood, urine and maternal breast milk (which represent recent exposures), and

scalp hair and nails (which represent long-term exposures) [83,287,395,418,428-434]. Both blood and urine may be used as bioindicators of MeHg and inorganic mercury exposures from fish consumption, the latter includes mercury formed by demethylation of MeHg in the body [435]. Also, mercury level in merconium (first stool) may be used as a convenient biomarker for evaluating antenatal exposure [118].

While blood mercury level does not correlate with urine level, both correlate with scalp hair level which offers a noninvasive, easy method of sample collection in children [436,437]. Using an average growth rate of 1.1 cm/mo. for scalp hair, a hair to blood ratio of 250 is an acceptable average value for safe mercury exposure [438]. MeHg in cord blood (for fetal exposure), and in hair and plasma (together with total mercury) are suitable biomarkers of mercury exposure in children [433,434,439]. Also, cord blood MeHg level significantly correlates with maternal hair mercury level [79].

Single blood mercury data should be treated with caution since it is not an indicator of long-term exposure [440]. Exhaled breath and sweat levels of mercury are important to measure since both could be significant routes for its elimination from the body [441]. However, there is no correlation between these two routes of mercury elimination and by the urinary pathway [442,443].

Total mercury levels in finger and toe nails correlate with scalp hair level attributable to fish consumption [1,430,444]. Further, hair from pubic and other regions of the body is also suitable for mercury analysis and the results correlate with scalp hair level [384,445,446]. Mercury concentration in saliva of children is generally below the limit of quantification. Thus, it is not suitable for monitoring mercury exposure [447].

An analysis of serum immune biomarkers in the fish-consuming teenagers from Amazonian Brazil found a positive association between mercury exposure and antinuclear antibodies and cytokines [448]. The results were similar to occupational exposure to elemental mercury vapor in adults (*e.g.,* ASGM workers) with symptoms of autoimmune dysfunction and systemic inflammation [449]. These serum biomarkers along with urinary ketoisoproporphyrin may be used to monitor long-term risks of prenatal mercury exposure in children [448,450,451].

In the US, CDC [452] and EPA [453] utilize biomonitoring of mercury in fish and other foods along with the environment to assess children's exposure to mercury. Such monitoring in New York City has identified skin care products as a source of inorganic mercury [316]. Similar biomonitoring of mercury is also being conducted in EU [3,114,230,231,281,433,447,454] . Japan [79,235] and India [280]. On a global basis, WHO, UN and other health organizations are conducting biomonitoring of mercury exposure of children in African, Asian and South American countries as well [6,60,271,373,448].

The mercury biomonitoring studies provide reference ranges to help determine whether children are exposed to higher (toxic) doses [132,252,260,261]. Additionally, such data are useful to evaluate the potential risks of prenatal environmental mercury exposure in different regions of the world [450].

Clinical analysis of mercury and chelation therapy

Cold vapor atomic absorption spectroscopy is a convenient laboratory method for the analysis of mercury in biological samples (detection limit 1 ng/L) [455]. A compilation of health-based guidance values for total mercury and MeHg in blood, urine and scalp hair of children and pregnant women is available [6]. While there is variation in the data from different countries, they are useful for comparative purposes [47]. Also, reviews of the low-dose mercury exposures and children's health [54,456], and guidance for identifying those at risk [60] are useful for reference. Interestingly, in recent years China, the most populous country in the world has reported relatively few cases of mercury poisoning of children [65].

Interpretation of results in children is relatively straightforward when biomarker mercury levels are highly elevated, but it becomes increasingly difficult as they approach normal values (*e.g.,* blood and urine mercury <10-20 μg/L) [344,418,457]. While diagnosing mercury poisoning in children can be challenging [458], it can be made with reasonable reliability and successfully treated with chelation therapy [34,459,460]. Although DMSA (succimer) is approved by FDA as the chelator for use in children [67,461], DMPS [348], N-acetyl cysteine [341], D-penicillamine and its N-acetyl derivative [34,462] can also be used effectively. Chelation therapy increases mercury excretion from the body and the common side effects are: abdominal cramps, drowsiness, dizziness, rash, pruritus (itchy skin), and flu-like symptoms [418]. Evaluation of chelation treatment with Se supplementation [463] and potential inappropriate use of chelating agents [464] are noteworthy.

Specific clinical signs and symptoms of acute and chronic poisoning by the three forms of mercury in children along with successful treatments employed are described below.

From exposure to elemental mercury vapor

As indicated earlier, home is the most common site for accidental inhalation of elemental mercury vapor by children (See Mercury exposure at homes section above).

From acute exposure to low to moderate doses of mercury vapor

Acute (short-term) exposure of children at low to moderate doses of elemental mercury vapor (≤ 1 μg/m^3 air) generally results in headache, dizziness, insomnia, dilated pupils with vision defects, peripheral neuropathy, and involuntary movements. However, fatality due to such acute exposure is unlikely.

Accidental small spill from broken fever thermometer in homes rarely results in mercury levels >1 μg/m^3 room air [61]. (Mercury vapor exposure from mercury-containing devices section above). Nevertheless, a recent mercury poisoning case mimicking an infectious disease in three siblings in an Atlanta, GA home has been attributed to mercury spill from a broken thermometer exasperated by repeated vacuum cleanings. The resulting blood mercury levels (>200 μg/L) needed chelation therapy with DMSA [67].

Also, school chemistry laboratories are potential sites for student exposure to low to moderate levels of mercury vapor (See Mercury Exposure at Schools section above).

From acute exposure to high doses of mercury vapor

The common symptoms of inhalation exposure to high doses of mercury vapor (>5-50 μg/m^3) are: salivation, swollen gingiva, fever, dry cough, dyspnea (shortness of breath), abdominal pain, nausea, vomiting and diarrhea [427], and death due to pulmonary dysfunction [55].

Although the exact fatal dose of mercury vapor is not known, exposure to >1-2 mg/m^3 air for a few hours can cause acute chemical bronchitis and pneumonitis [465]. Lung injury appears as hyaline membrane formation two hours after exposure, followed by extensive pulmonary fibrosis.

Just how quickly inhalation of high doses of mercury vapor can lead to death in infants is exemplified by the recent fatal poisoning of a 14-mo. girl in Denizli, Turkey [466]. Her sister had brought home mercury from the school without permission from teacher. After playing with it, she placed the liquid metal on heating stove and watched it vaporize. A day later, her baby sister got fever and died. The autopsy indicated necrotizing bronchitis, pneumonia or respiratory distress syndrome attributable to high mercury vapor exposure with death by cardiorespiratory collapse.

Similarly, exposure to high mercury vapor concentration of 0.193 mg/m^3 in kitchen air at a home in Fresno, CA, resulting from gold ore processing, has led to death of a 13-mo boy and his 38-yr mother [301]. Both had developed fatal respiratory distress within 48 h with blood mercury levels reaching 160 and 322 μg/L., respectively. Death of a 7-mo. infant under similar circumstances has also been reported earlier in Springfield, MA [302].

On a positive note, there is a report of accidental inhalation of mercury vapor of very high concentration (~0.37 mg/m^3 room air, produced by the home owner heating mercury-gold amalgam over a kitchen stove to recover gold) by a 19-yr. pregnant woman in Canada who 26 d later delivered a healthy infant with no detectable clinical abnormalities [303]. She was admitted to the hospital after 6 h of mercury exposure with paroxysmal cough, dyspnea, chest pain, nausea and vomiting. Three other children, ages 16 mos. to 7 yr., residing in the same bungalow were also treated for mercury poisoning with similar symptoms. Fortunately, in this case, exposed mother, newborn and all three children fully recovered after chelation therapy with D-penicillamine. Similarly, a 3-mo. infant in Shanghai, China was poisoned by inhalation of high concentration of mercury vapor which resulted in pneumothorax (collapsed lung) and respiratory failure 2d after exposure. She was successfully treated with DMPS chelation therapy [467].

From chronic exposure to low, moderate or high doses of mercury vapor

Children chronically exposed (3-4 mos.) to low levels of mercury vapor (≤5 μg/m^3 room air) are known to display psychomotor regression (restlessness), auto-aggression behavior (repeated biting of objects or own hands), areflexia (absence of muscle reflex response), ataxia (lack of coordination and balance, such as unable to stand up), erythema, acrodynia, gingivitis (gum disease characterized by irritation, redness and swelling), impaired sensation with hypertension, memory loss and kidney abnormalities [55-57,60,61,468].

Two cases of such psychomotor and auto aggression behaviors are well-documented: 1) a 11-mo.-old boy exposed to mercury spill from a broken thermometer [469] and 2) a 9-yr.-old boy who dismantled a blood pressure monitor and spilled mercury on his bed and carpeted floor [470]. Their mercury vapor exposures were aggravated by repeated vacuum cleaning. Following medical intervention (DMPS chelation therapy) and proper remediation of mercury contamination of their homes, health of both boys returned to normal in 6 mos.

Also, prolonged exposure to moderate level of mercury vapor (≤ 50 μg/m^3 room air) can cause classic mercury poisoning characterized by a triad of signs: tremor, erethism and gingivitis [471]. One such case involved three siblings who were chronically exposed (30-60 d) to mercury vapor in a Grand Rapids, MI home due to a large spill (~20 ml of elemental mercury, resulting in 10-40 μg/m^3 mercury in room air) [472]. They were hospitalized and successfully treated by chelation therapy. In another case of a 10-yr. child in Tehran, Iran who was exposed to mercury vapor at home for 20 days (mercury in blood, 27.7 μg/L and urine, 34.4 μg/L) demonstrated acrodynia, seizure, and visual impairment [473]. The patient recovered after 9 months of treatment with D-penicillamine. The initial brain MRI showed multiple hyperintense lesions in cerebral white matter, left globus pallidus and putamen, and all were resolved with chelation therapy.

WHO [60] lists the following health effects of chronic exposure to various concentrations of mercury in breathing air: >80 μg/m^3 with urine mercury >100 μg/g creatinine: tremor, erethism and proteinuria; 25-80 μg/m^3 with urine mercury: 30-100 μg creatinine: tremor, psychomotor disorder, irritability, fatigue and anorexia; 25-35 μg/g creatinine: tremor and <30 μg/g creatinine: above listed effects, usually mild and in sensitive individuals only.

ATSDR has set a minimum risk level of 0.2 μg/m^3 for mercury in residential air [86]. The following guideline for managing patients exposed to elemental mercury vapor may be used [474]: acute poisoning cases with cough, dyspnea and chest pain, for immediate referral to ER (Grade D) and those with symptoms of chronic toxicity (rash, tremor and weight loss) or exposed to high concentrations of mercury vapor but without dyspnea, for evaluation at a healthcare facility (Grade C).

From exposure to organic mercury compounds

Methyl, ethyl and phenyl derivatives of mercury are of exposure concern to infants and children. While contaminated fish consumption is the major source of MeHg exposure, the use of ethyl and phenyl derivatives as preservative, fungicide and antibacterial agents accounts for their exposures [423]. MeHg is more toxic than the other two organic derivatives of mercury [475].

From low to moderate pre-and postnatal exposure to MeHg

In infants, pre and postnatal (via breastfeeding) exposures to MeHg from maternal consumption of fish are chronic in nature and best assessed by toenail total mercury analysis (safe level ≤ 0.27 μg/g) [1].

The major adverse health effects of low-level prenatal MeHg exposure are diminished fetal and infant growth, and neurodevelopmental deficits in language, learning, attention span, vision and motor activities [55,419,476-478]. At moderate level, chronic MeHg exposure may cause: abnormal reflexes, irritability, cognitive deficits, delayed learning, blindness, microcephaly and cerebral palsy [479]. These severe neurotoxic effects occur when maternal hair levels of mercury reach >6 µg/g (or ~24 µg/L blood) [480]. The lowest MeHg level in the brain tissue that could cause neuropathological damage is 12 µg/g [422]. MeHg from fish is a risk factor for age-related cataracts since it readily accumulates in the eye lens [342,421].

From high prenatal exposure to MeHg

Prenatal exposure to high levels of MeHg (maternal blood levels 40-50 µg/L) during the 1970's mass poisoning in Japan (due to mercury containing industrial waste discharged into river water used for domestic purpose) has caused irreversible damage to fetal CNS resulting in blindness, deafness, cerebral palsy, impaired growth and severe intellectual disability [8,378,479].

ADHD in children caused by maternal MeHg exposure can be treated with the common antidepressant fluoxetine (Prozac) [103,481].

From high postnatal exposure to MeHg

Acute and chronic exposures of children to high levels of MeHg can cause ataxia, dysarthria, visual deficits, hearing loss, peripheral neuropathy, involuntary movements and even death [55,79,80,83,479].

While high-level MeHg exposures are rare, such poisoning on a large-scale has occurred in Iraq in 1971-1972 due to accidental distribution of seed grain treated with a MeHg-based fungicide meant for planting only [55,424,482]. Also, the clinical details of poisoning of a New Mexico family in the US due to the consumption of a hog fed seed grain treated with MeHg fungicide are available [483,484]. Further, extensive poisoning by consumption of fish highly contaminated with MeHg has occurred during the two major industrial disasters in Japan (1953 and 1964-1965). MeHg has a latency period of ~1 mo. after exposure and its lethal dose is 20–60 mg/kg bw with death occurring 2-4 wks after the onset of symptoms [8,80,419].

Information for physicians on recognizing and preventing overexposure [485] and risk assessment [486] of MeHg from fish consumption in children is available.

From acute exposure to ethylmercury (EtHg) in vaccines

EtHg is a component of preservative thimerosal (sodium ethylmercury thiosalicylate) used in children's vaccines. However, it is no longer of exposure concern to children in the US since FDA has banned its use in 1999 [55]. In children, iatrogenic acute exposure to EtHg from vaccines (~25 µg mercury/vaccine dose equivalent to that in a 3-oz can of tuna) usually leads to blood mercury levels below the EPA safety limit of 5.8 µg/L. The vaccine-derived mercury in the body is completely eliminated *via* stool by 60 d [308,487].

For Amazonian infants in the ASGM region who are exposed to environmental mercury and MeHg from breast milk and fish diet, additional burden of EtHg from vaccines is relevant only to early neurobehavioral deficits (as measured by GDS scores at 6 mo.) and such deficits are caught up by age 5 yr. [417]. However, the thimerosal-preserved vaccines do increase breastfed infant's hair mercury level [434,488] and they are implicated in Kawasaki's Disease, an acute febrile multiorgan vasculitis that affects children <5 yr. [461].

Extensive studies of children who received thimerosal-containing vaccines have affirmed their safety [45]. Also, a toxicity review of EtHg used as a preservative in biological (*e.g.,* children's vaccines) and pharmaceutical (*e.g.,* ophthalmic solutions and antibiotic ear suspensions) preparations has attested to its safety [308,489].

From acute exposure to Phenylmercuric Acetate (PMA)

PMA ($C_6H_5HgOCOCH_3$) has been used as an antifungal agent in agriculture, mildew inhibitor in leather products and paints, and additive in eye drops and washes [490]. Also, it is currently used in nasal spray and hemorrhoid relief ointment [308].

Infants exposed to PMA from the fungicide contaminated diapers in Buenos Aires, Argentina have developed acrodynia with increased urinary excretion of γ-glutamyl transpeptidase, a sensitive marker enzyme for mercury toxicity [491]. Absorption of PMA through the skin made infants irritable resulting in profuse sweating, swelling and desquamation (skin peeling) of the extremities, cheeks and nose. Their urinary mercury levels were elevated >50 µg/L which returned to normal along with health after discontinuing contaminated diaper use.

From exposure to inorganic mercury compounds

Inorganic mercury compounds (salts and oxide) are widely used in cosmetics, herbal medicines and dietary supplements. They are water soluble, more reactive than elemental mercury and highly corrosive. Their usual exposure routes are through skin contact and by oral ingestion, the latter known to cause nausea, vomiting and severe abdominal pain [17,34]. Kidney is the primary organ for their accumulation and chronic exposure damages it (indicated by elevated urinary proteins) [34]. Also, the gums become soft and spongy, develop sores and teeth get loose with enhanced saliva flow. In common with other forms of mercury, inorganic compounds also cause neurological damage [492]. For most inorganic compounds, the acute lethal dose is 1-4 g (equivalent to 14-60 mg/kg bw).

There is a correlation between fish consumption and inorganic mercury levels (directly absorbed from fish or formed by demethylation of MeHg in the body) in blood and urine [435]. Also, increase in fetal inorganic mercury levels occurs with increasing number of maternal amalgam fillings [193].

Specific examples of inorganic mercury compounds that children are frequently exposed to are described below.

Mercurous bromide (Hg_2Br_2)

In herbal medical practice, Hg_2Br_2 along with its chloride analog (Hg_2Cl_2) (calomel) are used in popular remedies for bacterial and viral skin infections. FDA has issued strong warning about mercury poisoning of children linked to such usage by adults [493]. Children breathing mercury vapor released from these products when used by adults' exhibit irritability, tremors and other toxic symptoms.

Mercurous chloride (Hg_2Cl_2) (calomel)

Currently available in the US pharmacies, calomel is used in skin-lightening creams, as purgative, fungicide, and to treat skin infections and itching during chickenpox and other viral/bacterial infections. Formerly used in baby teething powder, calomel can cause mercury poisoning (acrodynia and erythema). Thus, a recent case of a 17-mo.-old toddler's mercury poisoning in an Arizona home was attributed to calomel in skin-lightening cream used by her mother and grandmother [314]. The child exhibited hypertension, fussiness, constipation and arthralgia (temporomandibular joint pain) with high mercury levels in blood (26 μg/L) and urine (243 μg/g creatinine). She was successfully treated with DMSA and the contaminated home needed remediation. Also, children in several California families who used such skin-lightening creams were exposed to mercury concentrations >ATSDR safe level, 1.0 $\mu g/m^3$ air [315].

Mercuric chloride ($HgCl_2$)

This mercury salt has been used as a topical anesthetic, to treat ulcers and syphilis; as disinfectant, pesticide and fungicide in agriculture; and as bleach and stabilizer in food industry [17,326]. The classic toxic symptoms of $HgCl_2$ are a combination of renal, GI and CNS impairments that may result in death [494].

Mercuric oxide (HgO)

Ointments containing 1% HgO have been a treatment of choice for *Phthiriasis palpebrarum* infection in the eyelids of children [495]. As described earlier (see Exposure from unregulated cosmetics, etc. section above), FDA allows its use in products intended for eye infections only. The HgO-containing skin whitening and anti-itch creams are currently sold in the US (online and in pharmacies). The use of such products by uninformed parents could put their children in harm's way. Thus, the skin application of a HgO ointment to treat infected eczema has resulted in fatal poisoning of a 4-month-old infant [496]. Death occurred after 32 d and toxic levels of mercury were found in blood, urine, cerebrospinal fluid and vital organs at autopsy.

Since 1996, the use of HgO containing button batteries in toys, watches, smart car keys, etc. is banned in the US [497]. The symptoms associated with ingestion of battery with or without HgO are relatively nonspecific (vomiting, abdominal pain, fever, diarrhea, respiratory distress and dysphagia), and making proper diagnosis can be challenging [498].

Effect of diet and nutrition on mercury poisoning of children

There is wide variation in the neurodevelopmental effects of early-life mercury exposures in children in different parts of the world. This is attributable to the differences in their diet and nutritional status [47,91,416,499].

Several dietary constituents are known to inhibit the adverse effects of mercury [9,86,90,179,227,418,500-503]. They decrease GI absorption and tissue uptake of mercury, and counteract the metal toxicity by their antioxidant activity. For example, tropical fruit consumption reduces mercury uptake in Brazilian children [504,505] and the high intake of vegetables with fish helps reduce MeHg toxicity in Australian children [242,243]. Also, a change in diet from predatory to planktivorous fish is responsible for decreased mercury exposure in reproductive-age women in Brazil due to lower MeHg and higher DHA levels in the latter diet [373]. In contrast, green tea and ethyl alcohol enhance fish MeHg toxicity [86,87].

Similarly, nutrition can play important role in protecting children from toxic effects of mercury. Thus, dietary nutrient Se protects children from mercury toxicity [506]. Conversely, mercury exposure in children with poor nutritional status reduces their response to immunization vaccines, *e.g.,* those in gold mining communities in Peruvian Amazon [507].

Common dietary constituents with modulatory effect on mercury toxicity are described below.

Selenium (Se)

The consumption of Se-rich Ocean fish (yellow fin, skipjack and Blue Marlin) has improved IQ in children by reversing MeHg-induced toxicity in the brain and neuroendocrine system [508]. Dietary Se acts as a scavenger of reactive free-radicals of mercury by forming stable and biologically inert Se-Hg complexes [506,509]. It also acts as a prophylactic or antidotal agent to prevent or reverse mercury toxicity [463,500,510]. Further, Se levels can be used as a bioindicator to monitor mercury exposure and toxicity [511].

Blood Se level increases when freshwater Peacock bass, a predatory species, is consumed with coconut pulp [512]. The Se health benefits can be maximized by preferentially consuming herbivorous (primarily feeding on plants) fish species [513] and Se-rich vegetables, such as cassava root, and Brazil and chest nuts [370,514]. Specifically, the cataractogenic effect of mercury may be offset by Se-rich diet [515].

However, higher amounts of dietary mercury could reduce the protective activity of Se-dependent antioxidant enzymes [516]. Thus, Se: mercury molar ratio >1:1 in fish is required to achieve protection against mercury-induced toxicity [277,517]. This ratio depends on what fish feed on and their geographic location, and it decreases with increase in fish size and age [291,518-521]. Further, larger fish (>90 cm) exhibit biomagnification of Se and mercury, while smaller ones (<80 cm) do not [522]. Farming is currently being utilized to improve quality and safety of fish by reducing MeHg level and enhancing Se content [51].

While maternal iron status in blood appears to be unrelated to MeHg-induced neurotoxicity [375], combined high levels of lead (>31.4 μg/L) and mercury (>12.7 μg/L) have been associated with chronic under-arousal psychopathology in adolescent boys [523].

Tropical fruits and other constituents rich in antioxidants

Recent epidemiological studies in Brazil found that consumption of common tropical fruits (*e.g.,* bananas and oranges) can reduce both short-and long-term mercury uptakes in the body (as reflected by ~30% decreases in blood and scalp hair mercury levels) [504,505]. Also, wheat barn reduces mercury concentration in the brain [83]. MeHg toxicity is counteracted by its binding with dietary: 1) antioxidants, *e.g.,* DHA in fish and eggs, ascorbic acid (Vitamin C) in fruits and vegetables, phenolic gingerols and shogaols in ginger, polyphenols in

coffee, tannic acid and flavonoids in tea, and 2) SH group containing glutathione in fruits and S-allyl cysteine compounds in garlic, ginger and turmeric. Such MeHg binding interferes with its absorption and enhances excretion from the body [48,105,504,524-526]. Thus, consuming broiled or fried fish with tea or coffee can lead to decreased bioaccessibility and enhanced excretion of MeHg contaminant [279,502]. The dietary DHA provided by egg yolk is more economical and convenient to consume compared to fish [105].

Annatto, the seed of South American shrub *Bixa orellana* L. is used for commercial production of butter, margarine, cheese and ice cream. It contains antioxidant carotenoid pigments with potential protective effect against MeHg toxicity [527].

Ethyl alcohol (alcohol)

In EU, children start drinking wine at age 12 to 14 yr. and in many other counties it is legal for 16-yr-old to drink alcoholic beverages. Alcohol consumption is known to decrease body retention of inhaled mercury vapor by enhancing its elimination in exhaled air [528,529]. This result in mercury: 1) storage reduced in lungs, 2) level lowered in blood and 3) storage increased in liver.

A study of US dentists has confirmed the inhibitory effect of alcoholic drinks on the body uptake of occupationally exposed mercury vapor (while working with dental amalgam) based on its decreased excretion in the urine [530]. Alcohol is an inhibitor of catalase enzyme which is essential for oxidizing elemental mercury before it is absorbed in the body. In contrast, alcohol consumption increases MeHg toxicity, especially in the kidney [83,87].

Processed foods

Blood inorganic mercury, attributable to processed food intake, is directly associated with lower blood glucose levels [531]. This can result in reduced risk factors for type 2 diabetes. Children are routinely exposed to trace amounts of $HgCl_2$, (used in food industry for bleaching flour, refining vegetable oil products, and as inhibitor of corn starch degradation) when they consume processed foods, especially those containing high fructose corn syrup [326]. The latter, when used with certain artificial food colors (*e.g.,* sunset yellow) can lead to loss of zinc which is essential for elimination of mercury from the body [90].

Additionally, high fat diet, pasteurized milk, white bread, French fries, cornstarch, wheat bran and flour have shown protective effect against mercury toxicity by enhancing its elimination from the body [82,313].

Besides dietary constituents and nutritional status, factors such as gender, genetics, pharmacodynamic variables, maternal smoking, co-exposure to other pollutants and local contexts along with socio-environmental variables may also affect individual child's vulnerability and response to similar mercury exposures [10,96,159,160,177,178,418,487,502].

Prevention of mercury poisoning of children

The pediatric exposure to mercury can be minimized by salubrious parents with the knowledge of its exposure sources and resources available to take preventive measures outlined in this review.

Also, pediatricians, family practitioners and other medical professionals involved in emergency and poison control management could play important role in educating parents on the exposure hazards of mercury. Further, school science teachers should be active partners in educating children on the toxicity and safe handling of mercury.

To assist the above groups, this review has provided latest information on the following topics:

1. Common sources of mercury exposure at home (broken fever thermometers, OTC and herbal medicines, dietary supplements, cosmetics, tainted toys and jewelry).
2. How to handle small mercury spills at home, such as from a broken fever thermometer.
3. Major mercury spills and other contamination issues at home.
4. Why parents should not extract gold from scrap materials at home that involves heating mercury.
5. Hazards of mercury used in religious and cultural ceremonies at home.
6. Science teachers in schools should store mercury securely under lock and maintain proper inventory.
7. Educating children in school that mercury is not a toy but a hazardous metal.
8. In school science laboratories, students should handle mercury only under the supervision of a teacher. Facemask and gloves are needed for safe handling of mercury.
9. Pediatricians and other medical professionals should familiarize themselves with sources of mercury contamination, signs and symptoms of poisoning by the different forms of mercury.
10. Which fish to consume that has low mercury content?
11. The role of dietary constituents, such as tropical fruits in counteracting mercury toxicity from contaminated fish consumption.
12. Check ingredient label for mercury before purchasing any product suspected of contamination.

In some schools in the US, instead of teaching students safe handling of mercury, it is being banned in science laboratories [532]. Since human crematoriums account for significant atmospheric mercury pollution (several mg/m^3 per cremation; India alone emits 1.4 tons/year) [13,352], extraction of amalgam filled teeth of the diseased prior to cremation is worth considering.

Conclusions

From Fresno, California in the US to Denizli, Turkey and Shanghai, China, mercury poisoning of children continues to be of public health concern around the world with ongoing reports of nervous system damage, critical organ toxicity, pulmonary edema and even death. Because of its ubiquitous nature,

mercury is currently considered as the third toxic substance in the global environment and its exposure in children is expected to continue indefinitely.

However, there is indication that such environmental mercury exposure of children is being reduced by the development of mercury-free consumer devices (*e.g.,* digital fever thermometer and LED light bulb) and materials (*e.g.,* synthetic dental fillings without mercury), alternate manufacturing and non-fossil power generating processes, and improved occupational safety measures. With the continued progress in these fronts, the prospects for curtailing environmental mercury poisoning of children around the globe are bright indeed. There is high hope for the latest discovery of bioremediation of MeHg-polluted soil and water by the common plant symbiotic fungus *Metarhizium robertsii* to provide a viable solution for the global environmental mercury pollution [533,534]. The fungus enzymes, MeHg demethylase and mercury ion reductase detoxify MeHg by breaking it down to less toxic metallic mercury (Hg^{O}).

References

1. World Health Organization. Children's exposure to mercury compounds. 2010.
2. Kessler R. The Minamata Convention on Mercury: a first step toward protecting future generations. Environ Health Perspect 2013; 121(10):304-9.
3. EU. Tackling Mercury Pollution in the EU and Worldwide. In-Depth Report 15, European Commission, Science for Environmental Policy, University of the West of England, Bristol, England, 2017.
4. Haugen AC, Schug TT, Collman G, et al. Evolution of DOHaD: the impact of environmental health sciences. J Dev Orig Health Dis 2015; 6(2):55-64.
5. NIEHS-WHO, Annual Report of NIEHS-WHO Collaborating Centre for Environmental Health Sciences, NIH, Bethesda, MD, 2020.
6. Ruggieri F, Majorani C, Domanico F, et al. Mercury in children: current state on exposure through human biomonitoring studies. Int J Environ Res Public Health 2017; 14(5):519.
7. Landrigan PJ, Miodovnik A. Children's health and the environment: an overview. Mt Sinai J Med 2011 ;78(1):1-0.
8. Rao GS. Fatal mercury poisoning cases in forensic practice. Int J Forensic Prac Res 2013; 3:7-12.
9. Rao GS, Hefferren JJ. Toxicity of Mercury. Biocompatibility of Dental Restorative Materials, CRC Press, Boca Raton, FL, 1982:19-40.
10. Basu N, Bastiansz A, Dorea JG, et al. Our evolved understanding of the human health risks of mercury. Ambio 2023; 52(5):877-96.
11. EPA, Mercury Emissions: The Global Context, EPA, Washington, DC, 2022.
12. Fowler BA, Zalups RK. Mercury, in: G.F. Norberg, M. Costa, (Eds.), Handbook on the Toxicology of Metal, Specific Metals, 5th ed Elsevier Scientific Publishing Co., New York, NY, 2021: 675-729
13. Tibau AV, Grube BD. Mercury contamination from dental amalgam. J Health Pollut 2019; 9(22):190612.
14. Horowitz HM, Jacob DJ, Amos HM, et al. Historical mercury releases from commercial products: Global environmental implications. Environ Sci Technol 2014; 48(17):10242-50.
15. Rice KM, Walker Jr EM, Wu M, et al. Environmental mercury and its toxic effects. J Prev Med Public Health 2014; 47(2):74.
16. Driscoll CT, Mason RP, Chan HM, et al. Mercury as a global pollutant: sources, pathways, and effects. Environ Sci Technol 2013; 47(10):4967-83.
17. Park JD, Zheng W. Human exposure and health effects of inorganic and elemental mercury. J Prev Med Public Health 2012; 45(6):344.
18. Ozuah PO. Mercury poisoning. Curr Probl Pediatr 2000; 30(3):91-9.
19. Rogan WJ. Environmental poisoning of children--lessons from the past. Environ Health Perspect 1995; 103:19-23.
20. Pirrone N, Cinnirella S, Feng X, et al. Global mercury emissions to the atmosphere from anthropogenic and natural sources. Atmos Chem Phys 2010; 10(13):5951-64.
21. Regnell O, Watras CJ. Microbial mercury methylation in aquatic environments: a critical review of published field and laboratory studies. Environ Sci Technol 2018; 53(1):4-19.
22. WHO, Mercury and Health, WHO, Geneva, Switzerland, 2017.
23. Zillioux EJ. Mercury in fish: history, sources, pathways, effects, and indicator usage. Ecol Indic 2015; 743-66.
24. Dietz R, Outridge PM, Hobson KA. Anthropogenic contributions to mercury levels in present-day Arctic animals—a review. Sci Total Environ 2009; 407(24):6120-31.
25. Basu N, Abass K, Dietz R, et al. The impact of mercury contamination on human health in the Arctic: A state of the science review. Sci Total Environ 2022; 831:154793.
26. Alava JJ, Cisneros-Montemayor AM, Sumaila UR, et al. Projected amplification of food web bioaccumulation of MeHg and PCBs under climate change in the Northeastern Pacific. Sci Rep 2018; 8(1):13460.
27. Liu M, Zhang Q, Cheng M, et al. Rice life cycle-based global mercury biotransport and human methylmercury exposure. Nat Commun 2019; 10(1):5164.
28. Hussain M, Muhammad S, Malik RN, et al. Status of heavy metal residues in fish species of Pakistan. Rev Environ Contam Toxicol 2014; 111-32.
29. Lando AM, Zhang Y. Awareness and knowledge of methylmercury in fish in the United States. Environ Res 2011; 111(3):442-50.
30. Zhang Y, Song Z, Huang S, et al. Global health effects of future atmospheric mercury emissions. Nat Commun 2021; 12(1):3035.

31. Budnik LT, Casteleyn L. Mercury pollution in modern times and its socio-medical consequences. Sci Total Environ 2019; 654:720-34.
32. Bellanger M, Pichery C, Aerts D, et al. Economic benefits of methylmercury exposure control in Europe: monetary value of neurotoxicity prevention. Environ Health 2013; 12(1):1-0.
33. Swain EB, Jakus PM, Rice G, et al. Socioeconomic consequences of mercury use and pollution. Ambio 2007; 45-61.
34. Bernhoft RA. Mercury toxicity and treatment: a review of the literature. J Environ Public Health 2012
35. Wigle DT. Child health and the environment. Oxford University Press 2003.
36. Grégoire DS, Poulain AJ. A physiological role for HgII during phototrophic growth. Nat Geosci 2016; 9(2):121-5.
37. WHO, Mercury in Drinking Water, WHO, Geneva, Switzerland, 2005.
38. Arrifano GD, Augusto-Oliveira M, Lopes-Araújo A, et al. Global human threat: the potential synergism between mercury intoxication and COVID-19. International Int J Environ Res Public Health 2023; 20(5):4207.
39. Chanihoon GQ, Afridi HI, Unar A, et al. Selenium and mercury concentrations in biological samples from patients with COVID-19. J Trace Elem Med Biol 2022; 73:127038.
40. Skalny AV, Lima TR, Ke T, et al. Toxic metal exposure as a possible risk factor for COVID-19 and other respiratory infectious diseases. Food Chem Toxicol 2020; 146:111809.
41. Skalny AV, Skalnaya MG, Bjørklund G, et al. Mercury as a possible link between maternal obesity and autism spectrum disorder. Med Hypotheses 2016; 91:90-4. 22.
42. Sly PD, Trottier BA, Bulka CM, et al. The interplay between environmental exposures and COVID-19 risks in the health of children. Environ Health 2021; 20(1):1-0.
43. Baughman TA. Elemental mercury spills. Environ Health Perspect 2006; 114(2):147-52.
44. Zeitz P, Orr MF, Kaye WE. Public health consequences of mercury spills: Hazardous Substances Emergency Events Surveillance system, 1993-1998. Environ Health Perspect 2002; 110(2):129-32.
45. FDA, White Paper: FDA Update/Review of Potential Adverse Health Risks Associated with Exposure to Mercury in Dental Amalgam, National Center for Toxicological Research, FDA, Silver Spring, 2017.
46. EPA, Task Force on Ritualistic Uses of Mercury Report, EPA, Washington, DC, 2002.
47. Davis MA, Gilbert-Diamond D, Karagas MR, et al. A dietary-wide association study (DWAS) of environmental metal exposure in US children and adults. PLoS One 2014; 9(9):104768.
48. González-Estecha M, Bodas-Pinedo A, Rubio-Herrera MÁ, et al. The effects of methylmercury on health in children and adults; national and international studies. Nutr Hosp 2014; 30(5):989-1007.
49. Mergler D, Anderson HA, Chan LH, et al. Methylmercury exposure and health effects in humans: a worldwide concern. Ambio 2007; 36(1):3-11.
50. Gerke B. The social life of Tsotel: processing mercury in contemporary Tibetan medicine. Asian Medicine 2013; 8(1):120-52.
51. Liang L, Gilkeson J, Bennett E, et al. A pilot survey of mercury in drugs, cosmetics and household products using reliable analytical methods. J Cosmet Dermatol Sci Appl 2013; 3(04):256.
52. Lie Ø, ed Improving Farmed Fish Quality and Safety. CRC Press, Boca Raton, FL 2008.
53. Lee R, Middleton D, Caldwell K, et al. A review of events that expose children to elemental mercury in the United States. Environ Health Perspect 2009; 117(6):871-8.
54. Ronchetti R, Zuurbier M, Jesenak M, et al. Children's health and mercury exposure. Acta Pediatr Suppl 2006; 95:36-44.
55. Counter SA, Buchanan LH. Mercury exposure in children: A review. Toxicol Appl Pharmacol 2004; 198(2):209-30.
56. Bose-O'Reilly S, McCarty KM, Steckling N, et al. Mercury exposure and children's health. Curr Probl Pediatr Adolesc Health Care 2010; 40(8):186-215.
57. Davidson PW, Myers GJ, Weiss B. Mercury exposure and child development outcomes. Pediatrics 2004; 113:1023-9.
58. Bernstein AS, Oken E, de Ferranti S, et al. Fish, shellfish, and children's health: an assessment of benefits, risks, and sustainability. Pediatrics 2019; 143(6):20190999.
59. EPA, Guidelines to Physicians in Conducting Mercury Medical Surveillance Programs, Pamphlet 156, Archive Document, First ed., EPA, Washington, DC, 1998.
60. WHO, Guidance for Identifying Populations at Risk from Mercury Exposure, WHO, Geneva, Switzerland, 2008.
61. Besser RE. Children's exposure to elemental mercury: a national review of exposure events. Centers for disease control and prevention 2009.
62. Gummin DD, Mowry JB, Beuhler MC, et al. 2020 annual report of the American association of poison control centers' national poison data system (NPDS): 38th annual report. Clin Toxicol 202; 59(12):1282-501.
63. Sobol E, Edwards E, Jones MR. Polansky, Children hospitalized after mercury contamination at New Briton home (Hartford, CT), 2022.
64. Clancy S, Wentzville child hospitalized with mercury poisoning; EPA investigates. 2021.
65. Yawei S, Jianhai L, Junxiu Z, et al. Epidemiology, clinical presentation, treatment, and follow-up of chronic mercury poisoning in China: a retrospective analysis. BMC Pharmacol Toxicol 2021; 22(1):25.
66. Rakete S, Asenbauer E, Böhm S, et al. Mercury poisoning of a 4-year-old child by indirect contact to a mercury-

containing facial cream: A case report. SAGE 2021; 9:2050313X211025227.

67. Atti SK, Silver EM, Chokshi Y, et al. All that glitters is not gold: Mercury poisoning in a family mimicking an infectious illness. Curr Probl Pediatr Adolesc Health Care 2020; 50(2):100758.
68. Young AC, Wax PM, Feng SY, et al. Acute elemental mercury poisoning masquerading as fever and rash. J Med Toxicol 2020; 16:470-6.
69. Güngör O, Özkaya AK, Kirik S, et al. Acute mercury poisoning in a group of school children. Pediatr Emerg Care 2019; 35(10):696-9.
70. Valido HC, Ferreira JP, Ibrahim MK, et al. Mercury poisoning: A case report. Clinica Chimica Acta. 2019;493: S241-S242.
71. Peshin SS, Gupta YK. Poisoning due to household products: A ten years retrospective analysis of telephone calls to the National Poisons Information Centre, All India Institute of Medical Sciences, New Delhi, India. J Forensic Leg Med 2018; 58:205-11.
72. EPA, Neurodevelopmental disorders, in: America's Children and the Environment, Third ed. 2015: 233-252.
73. World Health Organization. Principles for evaluating health risks in children associated with exposure to chemicals. World Health Organization 2006.
74. Bjørklund G, Chirumbolo S, Dadar M, et al. Mercury exposure and its effects on fertility and pregnancy outcome. Basic Clin Pharmacol Toxicol 2019; 125(4):317-27.
75. Leventakou V, Roumeliotaki T, Martinez D, et al. Fish intake during pregnancy, fetal growth, and gestational length in 19 European birth cohort studies. Am J Clin Nutr 2014; 99(3):506-16.
76. Leino O, Kiviranta H, Karjalainen AK, et al. Pollutant concentrations in placenta. Food Chem Toxicol 2013; 54:59-69.
77. Leino O, Karjalainen AK, Tuomisto JT. Effects of docosahexaenoic acid and methylmercury on child's brain development due to consumption of fish by Finnish mother during pregnancy: a probabilistic modeling approach. Food Chem Toxicol 2013; 54:50-8.
78. Fox DA, Grandjean P, de Groot D, et al. Developmental origins of adult diseases and neurotoxicity: epidemiological and experimental studies. Neurotoxicology 2012; 33(4):810-6.
79. Murata K, Sakamoto M, Nakai K, et al. Effects of methylmercury on neurodevelopment in Japanese children in relation to the Madeiran study. Int Arch Occup Environ Health 2004; 77:571-9.
80. Weiss B, Clarkson TW, Simon W. Silent latency periods in methylmercury poisoning and in neurodegenerative disease. Environ Health Perspect 2002; 110:851-4.
81. Ajsuvakova OP, Tinkov AA, Aschner M, et al. Sulfhydryl groups as targets of mercury toxicity. Coord Chem Rev 2020; 417:213343.
82. Bergman Å, Heindel JJ, Jobling S, et al. World Health Organization. State of the science of endocrine disrupting chemicals 2012. World Health Organization 2013.
83. NRC, Toxicological Effects of Methylmercury, National Research Council, National Academies Press, Washington, DC. 2000.
84. Díez S. Human health effects of methylmercury exposure. Rev Environ Contam Toxicol 2009; 111-32.
85. Farina M, Aschner M, Rocha JB. Oxidative stress in MeHg-induced neurotoxicity. Toxicol Appl Pharmacol 2011; 256(3):405-17.
86. Abdullah N. Mercury in the diet, absorption and bio accessibility. OA Lab J 7(10):1-15.
87. Clarkson TW, Magos L. The toxicology of mercury and its chemical compounds. Crit Rev Toxicol 2006; 36(8):609-62.
88. Bolger M, Carrington C. Methylmercury hazards and risks-what is the question? FDA, Washington DC. 1996.
89. Borum D, Manibusan MK, Schoeny R, et al. Water quality criterion for the protection of human health: methylmercury.
90. Dufault R, Schnoll R, Lukiw WJ, et al. Mercury exposure, nutritional deficiencies and metabolic disruptions may affect learning in children. Behav Brain Funct 2009; 5(1):1-5.
91. Chapman L, Chan HM. The influence of nutrition on methyl mercury intoxication. Environ Health Perspect 2000; 108:29-56.
92. Saavedra S, Fernández-Recamales Á, Sayago A, et al. Impact of dietary mercury intake during pregnancy on the health of neonates and children: a systematic review. Nutr Rev 2022; 80(2):317-28.
93. Boucher O, Muckle G, Jacobson JL, et al. Domain-specific effects of prenatal exposure to PCBs, mercury, and lead on infant cognition: results from the Environmental Contaminants and Child Development Study in Nunavik. Environ Health Perspect 2014; 122(3):310-6.
94. Levenson CW, Axelrad DM. Too much of a good thing? Update on fish consumption and mercury exposure. Nutr Rev 2006; 64(3):139-45.
95. Da Cunha LR, da Costa TH, Caldas ED. Mercury concentration in breast milk and infant exposure assessment during the first 90 days of lactation in a midwestern region of Brazil. Biol Trace Elem Res 2013; 151:30-7.
96. Marques RC, Dorea JG, Bastos WR, et al. Maternal mercury exposure and neuro-motor development in breastfed infants from Porto Velho (Amazon), Brazil. Int J Hyg Environ Health 2007; 210(1):51-60.
97. Zwierzchowski G, Ametaj BN. Minerals and heavy metals in the whole raw milk of dairy cows from different management systems and countries of origin: A meta-analytical study. J Agric Food Chem 2018; 66(26):6877-88.
98. Ajmi Rn, Ati Al, Zeki Hf, et al. Traceability of mercury in

infant formula milk powder as a full cycle to the expiration date using direct mercury analyzer DMA 80. Global Science Publications 2018; 20:S35-S44

99. CDC, Breastfeeding: Mercury, CDC, Atlanta, GA. 2021.

100. Eidelman AI, Schanler RJ, Johnston M, et al. Breastfeeding and the use of human milk. Pediatrics 2012; 129(3):827-41.

101. Mead MN. Contaminants in human milk: weighing the risks against the benefits of breastfeeding. Environ Health Perspect 2008; 116(10):427-34

102. Grandjean P, Landrigan PJ. Neurobehavioral effects of developmental toxicity. Lancet Neurol 2014; 13(3):330-8.

103. Ceccatelli S, Bose R, Edoff K, et al. Long-lasting neurotoxic effects of exposure to methylmercury during development. J Intern Med 2013; 273(5):490-7.

104. Marques RC, Dorea JG, Bernardi JV, et al. Maternal fish consumption in the nutrition transition of the Amazon Basin: Growth of exclusively breastfed infants during the first 5 years. Ann Hum Biol 2008; 35(4):363-77.

105. Echeverría F, Valenzuela R, Hernandez-Rodas MC, et al. Docosahexaenoic acid (DHA), a fundamental fatty acid for the brain: New dietary sources. Prostaglandins Leukot Essent Fatty Acids 2017; 124:1-0.

106. Baum SJ, Kris-Etherton PM, Willett WC, et al. Fatty acids in cardiovascular health and disease: a comprehensive update. J Clin Lipidol 2012; 6(3):216-34.

107. Rumbold DG, Engel M, Axelrad DM. Risk of ill-informed decision-making when choosing your favorite fish. Hum Ecol Risk Assess 2011; 17(5):1156-69.

108. Costa LG. Contaminants in fish: risk-benefit considerations. Arh Hig Rada Toksikol 2007; 58(3):367.

109. Hightower JM, Moore D. Mercury levels in high-end consumers of fish. Environ Health Perspect 2003; 111(4):604-8.

110. Emeny RT, Korrick SA, Li Z, et al. Prenatal exposure to mercury in relation to infant infections and respiratory symptoms in the New Hampshire Birth Cohort Study. Environ Res 2019; 171:523-9.

111. Frery N, Maury-Brachet R, Maillot E, et al. Gold-mining activities and mercury contamination of native Amerindian communities in French Guiana: key role of fish in dietary uptake. Environ Health Perspect 2001; 109(5):449-56.

112. Bloom NS. On the chemical form of mercury in edible fish and marine invertebrate tissue. Can J Fish Aquat Sci 1992; 49(5):1010-7.

113. Rice DC, Schoeny R, Mahaffey K. Methods and rationale for derivation of a reference dose for methylmercury by the US EPA. Risk Anal 2003; 23(1):107-15.

114. Sirot V, Guérin T, Mauras Y, et al. Methylmercury exposure assessment using dietary and biomarker data among frequent seafood consumers in France: CALIPSO study. Environ Res 2008; 107(1):30-8.

115. Tatsuta N, Nakai K, Sakamoto M, et al. Methylmercury exposure and developmental outcomes in Tohoku study of child development at 18 months of age. Toxics 2018; 6(3):49.

116. Iwai-Shimada M, Satoh H, Nakai K, et al. Methylmercury in the breast milk of Japanese mothers and lactational exposure of their infants. Chemosphere 2015; 126:67-72.

117. Castaño A, Cutanda F, Esteban M, et al. Fish consumption patterns and hair mercury levels in children and their mothers in 17 EU countries. Environ Res 2015; 141:58-68.

118. Jiang CB, Yeh CY, Lee HC, et al. Mercury concentration in meconium and risk assessment of fish consumption among pregnant women in Taiwan. Sci Total Environ 2010; 408(3):518-23.

119. NIH, Omega-3 Fatty Acids: Fact Sheets for Health Professional. NIH, Bethesda 2021.

120. Newberry SJ, Chung M, Booth M, et al. Omega-3 fatty acids and maternal and child health: an updated systematic review. Evid Rep Technol Assess 2016; (224):1-826.

121. Lauritzen L, Brambilla P, Mazzocchi A, et al. DHA effects in brain development and function. Nutrients 2016; 8(1):6.

122. Campoy C, Escolano-Margarit MV, Anjos T, et al. Omega 3 fatty acids on child growth, visual acuity and neurodevelopment. Br J Nutr 2012; 107:85-106.

123. Osendarp SJ. The role of omega-3 fatty acids in child development. Oilseeds and fats, Crops and Lipids 2011; 18(6):307-13.

124. Tom S. Fats and Fatty Acids in Human Nutrition. Report of an Expert Consultation. Food and Nutrition Paper 91. Nutr Sci 2011.

125. Jacobson JL, Jacobson SW, Muckle G, et al. Beneficial effects of a polyunsaturated fatty acid on infant development: evidence from the Inuit of Arctic Quebec. J Pediatr 2008; 152(3):356-64.

126. McGregor JA, Carlson SE, Hobel CJ, et al. Nutritional roles of omega-3 fatty acids during pregnancy and neonatal development. Obg Manag 2003.

127. FDA, Advice About Earing Fish, Updated June 8, 2022, FDA, Silver Spring 2022.

128. EPA, Advice about Eating Fish and Shellfish, EPA, Washington, DC 2021.

129. Zeilmaker MJ, Hoekstra J, van Eijkeren JC et al. Fish consumption during child bearing age: A quantitative risk–benefit analysis on neurodevelopment. Food Chem Toxicol 2013; 54:30-4.

130. Rasmussen RS, Nettleton J, Morrissey MT. A review of mercury in seafood: special focus on tuna. J Aquat Food Prod Technol 2005; 14(4):71-100.

131. Mozaffarian D, Wu JH. Omega-3 fatty acids and cardiovascular disease: effects on risk factors, molecular pathways, and clinical events. J Am Coll Cardiol 2011; 58(20):2047-67.

132. Oken E, Radesky JS, Wright RO, et al. Maternal fish intake during pregnancy, blood mercury levels, and child cognition at age 3 years in a US cohort. Am J Epidemiol 2008;

167(10):1171-81.

133. Sioen I, De Henauw S, Verbeke W, et al. Fish consumption is a safe solution to increase the intake of long-chain n-3 fatty acids. Public Health Nutr 2008; 11(11):1107-1116.

134. Brenna JT, Veramini B, Jensen RG, et al. Docosahexaenoic and arachidonic acid concentrations in human breast milk worldwide. Am J Clin Nutr 2007; 85(6):1457-64.

135. Mendez MA, Torrent M, Julvez J, et al. Maternal fish and other seafood intakes during pregnancy and child neurodevelopment at age 4 years. Public Health Nutr 2009; 12(10):1702-10.

136. Emmett PM, Jones LR, Golding J. Pregnancy diet and associated outcomes in the Avon Longitudinal Study of Parents and Children. Nutr Rev 2015; 73:154-74.

137. Carlson SE, Colombo J, Gajewski BJ, et al. DHA supplementation and pregnancy outcomes. Am J Clin Nutr 2013; 97(4):808-15.

138. Boucher O, Burden MJ, Muckle G, et al. Neurophysiologic and neurobehavioral evidence of beneficial effects of prenatal omega-3 fatty acid intake on memory function at school age. Am J Clin Nutr 2011; 93(5):1025-37.

139. Razzaghi H, Tinker SC. Seafood consumption among pregnant and non-pregnant women of childbearing age in the United States, NHANES 1999–2006. Food Nutr Res 2014; 58(1):23287.

140. Van Goor SA, Dijck-Brouwer DJ, Hadders-Algra M, et al. Human milk arachidonic acid and docosahexaenoic acid contents increase following supplementation during pregnancy and lactation. Prostaglandins Leukot Essent Fatty Acids 2009; 80(1):65-9.

141. Valenzuela A, Sanhueza BJ, Nieto S. Docosahexaenoic acid (DHA), essentiality and requirements: why and how to provide supplementation. Grasas Aceites 2006; 57(2):229-37.

142. Juber BA, Jackson KH, Johnson KB, et al. Breast milk DHA levels may increase after informing women: a community-based cohort study from South Dakota USA. Int Breastfeed J 2016; 12:1-9.

143. Nevins JE, Donovan SM, Snetselaar L, et al. Omega-3 fatty acid dietary supplements consumed during pregnancy and lactation and child neurodevelopment: a systematic review. J Nutr 2021; 151(11):3483-94.

144. Kvestad I, Hysing M, Kjellevold M, et al. Maternal cod intake during pregnancy and infant development in the first year of life: secondary analyses from a randomized controlled trial. J Nutr 2021; 151(7):1879-85.

145. Hamazaki K, Matsumura K, Tsuchida A, et al. Maternal dietary intake of fish and PUFAs and child neurodevelopment at 6 months and 1 year of age: a nationwide birth cohort—the Japan Environment and Children's Study (JECS). Am J Clin Nutr 2020; 112(5):1295-303.

146. Dunstan JA, Mitoulas LR, Dixon G, et al. The effects of fish oil supplementation in pregnancy on breast milk fatty acid composition over the course of lactation: a randomized controlled trial. Pediatr Res 2007; 62(6):689-94.

147. Saccone G, Saccone I, Berghella V. Omega-3 long-chain polyunsaturated fatty acids and fish oil supplementation during pregnancy: which evidence? J Matern Fetal Neonatal Med 2016; 29(15):2389-97.

148. Koletzko B, Lien E, Agostoni C, et al. The roles of long-chain polyunsaturated fatty acids in pregnancy, lactation and infancy: review of current knowledge and consensus recommendations. J Perinat Med 2008; 36(1):5-14.

149. Koletzko B, Boey CC, Campoy C, et al. Current information and Asian perspectives on long-chain polyunsaturated fatty acids in pregnancy, lactation, and infancy: systematic review and practice recommendations from an early nutrition academy workshop. Ann Nutr Metab 2014; 65(1):49-80.

150. Khandelwal S, Kondal D, Chaudhry M, et al. Effect of maternal docosahexaenoic acid (DHA) supplementation on offspring neurodevelopment at 12 months in India: a randomized controlled trial. Nutrients 2020; 12(10):3041.

151. Valent F, Mariuz M, Bin M, et al. Associations of prenatal mercury exposure from maternal fish consumption and polyunsaturated fatty acids with child neurodevelopment: a prospective cohort study in Italy. J Epidemiol 2013; 23(5):360-70.

152. Scholtens S, Wijga AH, Smit HA, et al. Long-chain polyunsaturated fatty acids in breast milk and early weight gain in breast-fed infants. Br J Nutr 2008; 101(1):116-21.

153. N. Stratakis, D.V, Conti, E. Borras, et al. Association of fish consumption with mercury exposure during pregnancy with metabolic health and inflammatory biomarkers in children. JAMA Netw Open 2020; 3(3):201007

154. Julvez J, Debes F, Weihe P, et al. Sensitivity of continuous performance test (CPT) at age 14 years to developmental methylmercury exposure. Neurotoxicol Teratol 2010; 32(6):627-32.

155. Halldorsson TI, Meltzer HM, Thorsdottir I, et al. Is high consumption of fatty fish during pregnancy a risk factor for fetal growth retardation? A study of 44,824 Danish pregnant women. Am J Epidemiol 2007; 166(6):687-96.

156. Jacobson JL, Muckle G, Ayotte P, et al. Relation of prenatal methylmercury exposure from environmental sources to childhood IQ. Environ Health Perspect 2015; 123(8):827-33.

157. Jedrychowski W, Jankowski J, Flak E, et al. Effects of prenatal exposure to mercury on cognitive and psychomotor function in one-year-old infants: epidemiologic cohort study in Poland. Ann Epidemiol 2006; 16(6):439-47.

158. Jedrychowski W, Perera F, Rauh V, et al. Fish intake during pregnancy and mercury level in cord and maternal blood at delivery: an environmental study in Poland. Int J Occup Med Environ Health 2007; 20(1).

159. Ramón R, Murcia M, Ballester F, et al. Prenatal exposure to mercury in a prospective mother–infant cohort study in a Mediterranean area, Valencia, Spain. Sci Total Environ 2008;

392(1):69-78.

160. Spulber S, Rantamäki T, Nikkilä O, et al. Effects of maternal smoking and exposure to methylmercury on brain-derived neurotrophic factor concentrations in umbilical cord serum. Toxicol Sci 2010; 117(2):263-9.

161. Basu N, Tutino R, Zhang Z, et al. Mercury levels in pregnant women, children, and seafood from Mexico City. Environ Res 2014; 135:63-9.

162. Starling P, Charlton K, McMahon AT, et al. Fish intake during pregnancy and fetal neurodevelopment—a systematic review of the evidence. Nutrients 2015; 7(3):2001-14.

163. Avella-Garcia CB, Julvez J. Seafood intake and neurodevelopment: a systematic review. Curr Environ Health Rep 2014; 1:46-77.

164. Cardoso C, Afonso C, Lourenço H, et al. Seafood consumption health concerns: The assessment of methylmercury, selenium, and eicosapentaenoic+ docosahexaenoic fatty acids intake. Food control 2013; 34(2):581-8.

165. Hellberg RS, DeWitt CA, Morrissey MT. Risk-benefit analysis of seafood consumption: A review. Compr. Rev Food Sci Food Saf 2012; 11(5):490-517.

166. Rheimberger CM, Hammitt JK. Risk trade-offs in fish consumption: a public health perspective. Environ Sci Technol 2012; 46(22):12337-46.

167. Sagiv SK, Thurston SW, Bellinger DC, et al. Prenatal exposure to mercury and fish consumption during pregnancy and attention-deficit/hyperactivity disorder–related behavior in children. Arch Pediatr Adolesc Med 2012; 166(12):1123-31.

168. Mahaffey KR, Sunderland EM, Chan HM, et al. Balancing the benefits of n-3 polyunsaturated fatty acids and the risks of methylmercury exposure from fish consumption. Nutr Rev 2011; 69(9):493-508.

169. Genuis SJ. To sea or not to sea: benefits and risks of gestational fish consumption. Reprod Toxicol 2008; 26(2):81-5.

170. Davidson PW, Cory-Slechta DA, Thurston SW, et al. Fish consumption and prenatal methylmercury exposure: cognitive and behavioral outcomes in the main cohort at 17 years from the Seychelles child development study. Neurotoxicology 2011; 32(6):711-7.

171. Dack K, Fell M, Taylor CM, et al. Prenatal mercury exposure and neurodevelopment up to the age of 5 years: A systematic review. Int J Environ Res Public Health 2022; 19(4):1976.

172. Budtz-Jørgensen E, Grandjean P, Weihe P. Separation of risks and benefits of seafood intake. Environ Health Perspect 2007; 115(3):323-7.

173. Goodman M, Barraj LM, Mink PJ, et al. Estimating uncertainty in observational studies of associations between continuous variables: example of methylmercury and neuropsychological testing in children. Epidemiol Perspect Innov 2007; 4:1-3.

174. Julvez J, Smith GD, Golding J, et al. Prenatal methylmercury exposure and genetic predisposition to cognitive deficit at age 8 years. Epidemiology 2013; 24(5):643.

175. Ng S, Lin CC, Hwang YH, et al. Mercury, APOE, and children's neurodevelopment. Neurotoxicology 2013; 37:85-92.

176. Andreoli V, Sprovieri F. Genetic aspects of susceptibility to mercury toxicity: an overview. Int J Environ Res Public Health 2017; 14(1):93.

177. González-Estecha M, Bodas-Pinedo A, Guillén-Pérez JJ, et al. Methylmercury exposure in the general population; toxicokinetics; differences by gender, nutritional and genetic factors. Nutr Hosp 2014; 30(5):969-88.

178. Julvez J, Grandjean P. Genetic susceptibility to methylmercury developmental neurotoxicity matters. Front Genet 2013; 4:278.

179. Canuel R, de Grosbois SB, Atikesse L, et al. New evidence on variations of human body burden of methylmercury from fish consumption. Environ Health Perspect 2006; 114(2):302-6.

180. Marques A, Lourenço HM, Nunes ML, et al. New tools to assess toxicity, bioaccessibility and uptake of chemical contaminants in meat and seafood. Food Res Int 2011; 44(2):510-22.

181. Thurston SW, Bovet P, Myers GJ, et al. Does prenatal methylmercury exposure from fish consumption affect blood pressure in childhood?. Neurotoxicology 2007; 28(5):924-30.

182. Grandjean P, Murata K, Budtz-Jørgensen E, et al. Cardiac autonomic activity in methylmercury neurotoxicity: 14-year follow-up of a Faroese birth cohort. The J Pediatr 2004; 144(2):169-76.

183. Genchi G, Sinicropi MS, Carocci A, et al. Mercury exposure and heart diseases. Int J Environ Res Public Health 2017; 14(1):74.

184. Fernandes Azevedo B, Barros Furieri L, Peçanha FM, et al. Toxic effects of mercury on the cardiovascular and central nervous systems. J Biomed Biotechnol 2012; 2012.

185. Roman HA, Walsh TL, Coull BA, et al. Evaluation of the cardiovascular effects of methylmercury exposures: current evidence supports development of a dose–response function for regulatory benefits analysis. Environ Health Perspect 2011; 119(5):607-14.

186. Virtanen JK, Rissanen TH, Voutilainen S, et al. Mercury as a risk factor for cardiovascular diseases. J Nutr Biochem 2007; 18(2):75-85.

187. Hu XF, Lowe M, Chan HM. Mercury exposure, cardiovascular disease, and mortality: A systematic review and dose-response meta-analysis. Environ Res 2021; 193:110538.

188. Guallar E, Sanz-Gallardo MI, Veer PV, et al. Mercury, fish oils, and the risk of myocardial infarction. N Engl J Med 2002; 347(22):1747-54.

189. Yoshizawa K, Rimm EB, Morris JS, et al. Mercury and the risk of coronary heart disease in men. N Engl J Med 2002; 347(22):1755-60.

190. Zhang B, Xiong K, Cai J, et al. Fish consumption and coronary heart disease: a meta-analysis. Nutrients 2020; 12(8):2278.

191. Yinko SS, Stark KD, Thanassoulis G, et al. Fish consumption

and acute coronary syndrome: a meta-analysis. Am J Med 2014; 127(9):848-57.

192. König A, Bouzan C, Cohen JT, et al. A quantitative analysis of fish consumption and coronary heart disease mortality. Am J Prev Med 2005; 29(4):335-46.

193. Bjornberg KA, Vahter M, Petersson-Grawe K, et al. Methyl mercury and inorganic mercury in Swedish pregnant women and in cord blood: influence of fish consumption. Environ Health Perspect 2003; 111(4):637-41.

194. Palmieri J.R, Guthrie T, Kaur G, et al., Implications and significance of mercury in rice. J Food Nutr Metab 2020; 1-5.

195. Rothenberg SE, Windham-Myers L, Creswell JE. Rice methylmercury exposure and mitigation: a comprehensive review. Environ Res 2014; 133:407-23.

196. Zhao L, Meng B, Feng X. Mercury methylation in rice paddy and accumulation in rice plant: a review. Ecotoxicol Environ Saf 2020; 195:110462.

197. Horvat M, Nolde N, Fajon V, et al. Total mercury, methylmercury and selenium in mercury polluted areas in the province Guizhou, China. Sci Total Environ 2003; 304(1-3):231-56.

198. Arunakumara KK, Walpola BC, Yoon MH. Current status of heavy metal contamination in Asia's rice lands. Rev Environ Sci Biotechnol 2013; 12:355-77.

199. Meng B, Feng X, Qiu G, et al. The process of methylmercury accumulation in rice. Environ Sci Technol 2011; 45(7):2711-7.

200. Meng B, Feng X, Qiu G, et al. Inorganic mercury accumulation in rice. Environ Toxicol Chem 2012; 31(9):2093-8.

201. Rothenberg SE, Feng X, Dong B, et al. Characterization of mercury species in brown and white rice (Oryza sativa L.) grown in water-saving paddies. Environ Pollut 2011; 159(5):1283-9.

202. Rothenberg SE, Korrick SA, Liu J, et al. Maternal methylmercury exposure through rice ingestion and child neurodevelopment in the first three years: a prospective cohort study in rural China. Environ Health 2021; 20(1):50.

203. Zhang H, Feng X, Larssen T, et al. In inland China, rice, rather than fish, is the major pathway for methylmercury exposure. Environ Health Perspect 2010; 118(9):1183-8.

204. Rothenberg SE, Yin R, Hurley JP, et al. Stable mercury isotopes in polished rice (Oryza sativa L.) and hair from rice consumers. Environ Sci Technol 2017; 51(11):6480-8.

205. Li P, Feng X, Qiu G. Methylmercury exposure and health effects from rice and fish consumption: a review. Int J Environ Res Public Health 2010; 7(6):2666-91.

206. Lin Y, Vogt R, Larssen T. Environmental mercury in China: a review. Environ Toxicol Chem 2012; 31(11):2431-44.

207. Ahmed MS, Biswas MM, Mottalib MA, et al. Translocation of heavy metals from industry into vegetables and crops through water and soil of Mokesh Beel in Bangladesh and their impact on human body. IOSR J Environ Sci Toxicol Food Technol 2019;13(5):59-71.

208. Agrawal SB, Singh A, Sharma RK, et al. Bioaccumulation of heavy metals in vegetables: A threat to human health. Terrestrial and aquatic environmental toxicology 2007; 1(2):13-23.

209. Liu X, Song Q, Tang Y, et al. Human health risk assessment of heavy metals in soil–vegetable system: a multi-medium analysis. Sci Total Environ 2013; 463:530-40.

210. Lui WX, Li HH, Li SR, et al. Heavy metal accumulation of edible vegetables cultivated in agricultural soil in the suburb of Zhengzhou City, People's Republic of China. Bull Environ Contam Toxicol 2006; 76(1):163-70.

211. Alonso J, Salgado MJ, Garcia MA, et al. Accumulation of mercury in edible microfungi-influence of some factors. Arch Environ Contam Toxicol 2000; 38:158-62.

212. Li R, Wu H, Ding J, et al. Mercury pollution in vegetables, grains and soils from areas surrounding coal-fired power plants. Sci Rep 2017; 7(1):46545.

213. Sattar MU, Khan MA, Khalil AA, et al. Mitigation of heavy metals in vegetables through washing with house hold chemicals. Int J Agric Sci Res 2013; 3(5):1-1.

214. Khalili Tilami S, Sampels S. Nutritional value of fish: lipids, proteins, vitamins, and minerals. Rev Fish Sci Aquac 2018; 26(2):243-53.

215. Schwartz J. Mercury from fish does not reduce children's IQs. Environ Health Perspect 2006; 114(7):399-400.

216. Trasande L, Landrigan PJ, Schechter CB. Children's IQs: Trasande et al. Respond. Environ Health Perspect 2006; 114(7): A400-1.

217. González-Estecha M, Bodas-Pinedo A, Guillén-Pérez JJ, et al. Consensus document on the prevention of methylmercury exposure in Spain: Study group for the prevention of Me-Hg exposure in Spain (GEPREM-Hg). J Trace Elem Med Biol 2015; 32:122-34.

218. ATSDR. Mercury-Tox FAQs. US DHHS, PHS, Atlanta, GA 1999.

219. Nunes E, Cavaco A, Carvalho C. Children's health risk and benefits of fish consumption: risk indices based on a diet diary follow-up of two weeks. Journal of J Toxicol Environ Health A 2014; 77(1-3):103-14.

220. Alberta S. Human Health Risk Assessment. Alberta Health and Wellness 2009.

221. Patel NB, Xu Y, McCandless LC, et al. Very low-level prenatal mercury exposure and behaviors in children: the HOME Study. Environ Health 2019; 18(1):1-2.

222. Deroma L, Parpinal M, Tognin V, et al. Neuropsychological assessment at school-age and prenatal low-level exposure to mercury through fish consumption in an Italian birth cohort living near a contaminated site. Int J Hyg Environ Health 2013; 216(4):486-93.

223. Kalogeropoulos N, Karavoltsos S, Sakellari A, et al. Heavy metals in raw, fried and grilled Mediterranean finfish and shellfish. Food Chem Toxicol 2012; 50(10):3702-8.

224. Hajeb P, Sloth JJ, Shakibazadeh SH, et al. Toxic elements in food: occurrence, binding, and reduction approaches. Compr Rev Food Sci Food Saf 2014; 13(4):457-72.

225. Govt. of Canada. Evaluation of the Effectiveness of Risk Management Measures for Mercury. Environment and Climate Change Canada 2020; 11-18.

226. Ethier AA, Muckle G, Bastien C, et al. Effects of environmental contaminant exposure on visual brain development: a prospective electrophysiological study in school-aged children. Neurotoxicology 2012; 33(5):1075-85.

227. Lemire M, Kwan M, Laouan-Sidi AE, et al. Local country food sources of methylmercury, selenium and omega-3 fatty acids in Nunavik, Northern Quebec. Sci Total Environ 2015; 509:248-59.

228. Walker JB, Houseman J, Seddon L, et al. Maternal and umbilical cord blood levels of mercury, lead, cadmium, and essential trace elements in Arctic Canada. Environ Res 2006; 100(3):295-318.

229. Després C, Beuter A, Richer F, et al. Neuromotor functions in Inuit preschool children exposed to Pb, PCBs, and Hg. Neurotoxicol Teratol 2005; 27(2):245-57.

230. Lutter R, Irwin E. Mercury in the environment: a volatile problem. Environ Sci Policy 2002; 44(9):24-40.

231. Cullen E, Evans DS, Davidson F, et al. Mercury exposure in Ireland: results of the DEMOCOPHES human biomonitoring study. Int J Environ Res Public Health 2014; 11(9):9760-75.

232. Brambilla G, Abete MC, Binato G, et al. Mercury occurrence in Italian seafood from the Mediterranean Sea and possible intake scenarios of the Italian coastal population. Regul Toxicol Pharmacol 2013; 65(2):269-77.

233. Freire C, Ramos R, Lopez-Espinosa MJ, et al. Hair mercury levels, fish consumption, and cognitive development in preschool children from Granada, Spain. Environ Res 2010; 110(1):96-104.

234. Díez S, Delgado S, Aguilera I, et al. Prenatal and early childhood exposure to mercury and methylmercury in Spain, a high-fish-consumer country. Arch Environ Contam Toxicol 2009; 56:615-22.

235. Ortega-García JA, Rodriguez K, Calatayud M, et al. Estimated intake levels of methylmercury in children, childbearing age and pregnant women in a Mediterranean region, Murcia, Spain. Eur J Pediatr 2009; 168:1075-80.

236. Ilmiawati C, Yoshida T, Itoh T, et al. Biomonitoring of mercury, cadmium, and lead exposure in Japanese children: a cross-sectional study. Environ Health Prev Med 2015; 20:18-27.

237. Rahbar MH, Samms-Vaughan M, Loveland KA, et al. Seafood consumption and blood mercury concentrations in Jamaican children with and without autism spectrum disorders. Neurotox Res 2013; 23:22-38.

238. McKean SJ, Bartell SM, Hansen RL, et al. Prenatal mercury exposure, autism, and developmental delay, using pharmacokinetic combination of newborn blood concentrations and questionnaire data: a case control study. Environ Health 2015; 14(1):1-2.

239. Corbett SJ, Poon CC. Toxic levels of mercury in Chinese infants eating fish congee. Med J Aust 2008; 188(1):59-60.

240. Cheuk DK, Wong V. Attention-deficit hyperactivity disorder and blood mercury level: a case-control study in Chinese children. Neuropediatrics 2006; 37(04):234-40.

241. Rahmawaty S, Charlton K, Lyons-Wall P, et al. Dietary intake and food sources of EPA, DPA and DHA in Australian children. Lipids 2013; 48:869-77.

242. Rahmawaty S, Lyons-Wall P, Batterham M, et al. Food patterns of Australian children ages 9 to 13 y in relation to ω-3 long chain polyunsaturated intake. Nutrition 2014; 30(2):169-76.

243. Yaktine AL, Nesheim MC, James CA. Nutrient and contaminant tradeoffs: exchanging meat, poultry, or seafood for dietary protein. Nutr Rev 2008; 66(3):113-22.

244. Heaton AE, Meldrum SJ, Foster JK, et al. Does docosahexaenoic acid supplementation in term infants enhance neurocognitive functioning in infancy? Front Hum Neurosci 2013; 7:774.

245. Devlin AM, Chau CM, Dyer R, et al. Developmental outcomes at 24 months of age in toddlers supplemented with arachidonic acid and docosahexaenoic acid: results of a double blind randomized, controlled trial. Nutrients 2017; 9(9):975.

246. Qawasmi A, Landeros-Weisenberger A, Leckman JF, et al. Meta-analysis of long-chain polyunsaturated fatty acid supplementation of formula and infant cognition. Pediatrics 2012; 129(6):1141-9.

247. Ciccone MM, Scicchitano P, Gesualdo M, et al. The role of omega-3 polyunsaturated fatty acids supplementation in childhood: a review. Recent Pat Cardiovasc Drug Discov 2013; 8(1):42-55.

248. Houlihan J, Brody C, What's in my baby food?. 2013.

249. Hightower JM, Brown DL. Mercury concentrations in fish jerky snack food: Marlin, Ahi, and Salmon. Environ Health 2011; 10:1-4.

250. House of Representatives US. Baby foods are tainted with dangerous levels of arsenic, lead, cadmium, and mercury. Schober SE, Sinks TH, Jones RL, et al. Blood mercury levels in US children and women of childbearing age, 1999-2000. JAMA 2003; 289(13):1667-74.

251. FDA, Closer to Zero: Action Plan for Baby Foods. Silver Spring 2021.

252. Schober SE, Sinks TH, Jones RL, et al. Blood mercury levels in US children and women of childbearing age, 1999-2000. JAMA 2003; 289(13):1667-74.

253. Mahaffey KR, Clickner RP, Bodurow CC. Blood organic mercury and dietary mercury intake: National Health and Nutrition Examination Survey, 1999 and 2000. Environ Health Perspect 2004; 112(5):562-70.

254. Schaefer AM, Jensen EL, Bossart GD, et al. Hair mercury

concentrations and fish consumption patterns in Florida residents. Int J Environ Res Public Health 2014; 11(7):6709-26.

255. Schaefer AM, Zoffer M, Yrastorza L, et al. Mercury exposure, fish consumption, and perceived risk among pregnant women in coastal Florida. Int J Environ Res Public Health 2019; 16(24):4903.

256. Burch JB, Wagner Robb S, Puett R, et al. Mercury in fish and adverse reproductive outcomes: results from South Carolina. Int J Health Geogr 2014; 13(1):1-1.

257. Nair A, Jordan M, Watkins S, et al. Fish consumption and hair mercury levels in women of childbearing age, Martin County, Florida. Matern Child Health J 2014; 18:2352-61.

258. Wells EM, Jarrett JM, Lin YH, et al. Body burdens of mercury, lead, selenium and copper among Baltimore newborns. Environ Res 2011; 111(3):411-7.

259. Wathen JB, Lazorchak JM, Olsen AR, et al. A national statistical survey assessment of mercury concentrations in fillets of fish collected in the US EPA national rivers and streams assessment of the continental USA. Chemosphere 2015; 122:52-61.

260. Nielsen SJ, Aoki Y, Kit BK, et al. More than half of US youth consume seafood and most have blood mercury concentrations below the EPA reference level, 2009–2012. J Nutr 2015; 145(2):322-7.

261. Mortensen ME, Caudill SP, Caldwell KL, et al. Total and methyl mercury in whole blood measured for the first time in the US population: NHANES 2011–2012. Environ Res 2014; 134:257-64.

262. Nunes E, Cavaco A, Carvalho C. Exposure assessment of pregnant Portuguese women to methylmercury through the ingestion of fish: Cross-sectional survey and biomarker validation. J Toxicol Environ Health A 2014; 77(1-3):133-42.

263. Turunen AW, Verkasalo PK, Kiviranta H, et al. Mortality in a cohort with high fish consumption. Int J Epidemiol 2008; 37(5):1008-17.

264. Hacon SS, Dorea JG, Fonseca MD, et al. The influence of changes in lifestyle and mercury exposure in riverine populations of the Madeira River (Amazon Basin) near a hydroelectric project. Int J Environ Res Public Health 2014; 11(3):2437-55.

265. Malm O, Dorea JG, Barbosa AC, et al. Sequential hair mercury in mothers and children from a traditional riverine population of the Rio Tapajos, Amazonia: Seasonal changes. Environ Res 2010; 110(7):705-9.

266. Oliveira RC, Dorea JG, Bernardi JV, et al. Fish consumption by traditional subsistence villagers of the Rio Madeira (Amazon): impact on hair mercury. Ann Hum Biol 2010; 37(5):629-42.

267. Marques RC, Bernardi JV, Dorea JG, et al. Fish consumption during pregnancy, mercury transfer, and birth weight along the Madeira River Basin in Amazonia. Int J Environ Res Public Health 2013; 10(6):2150-63.

268. Sousa JM, REIS I, CARVALHAL M. Assessment of the motor development of children poisoned with mercury. Gazz Med Ital 2014;173:1-2.

269. Fuentes-Gandara F, Pinedo-Hernández J, Marrugo-Negrete J, et al. Human health impacts of exposure to metals through extreme consumption of fish from the Colombian Caribbean Sea. Environ Geochem Health 2018; 40:229-42.

270. Marrugo-Negrete J, Vargas-Licona S, Ruiz-Guzmán JA, et al. Human health risk of methylmercury from fish consumption at the largest floodplain in Colombia. Environ Res 2020; 182:109050.

271. Gibb H, O'Leary KG, Sarkar SK, et al. Hair mercury concentrations in residents of Sundarban and Calcutta, India. Environ Res 2016; 150:616-21.

272. Mukherjee DP, Bhupander K. Assessment of Arsenic, Cadmium, and Mercury Level In: Commonly Consumed Coastal Fishes from Bay of Bengal, India. Food Sci Qual Manag 2011; 2.

273. Shingadia HU. Accretion of prospective minerals in few commercially imperative fishes collected from Versova fish landing center in western suburbs of Mumbai, India. IOSR J Environ Sci Toxicol Food Technol 2016; 10(3):25-32.

274. Ray D, Roy A, Bhat M, et al. Total mercury and methylmercury in commercial marine species from the Goa coast: Constraints on risk assessment and environmental issues. Indian J Geo Mar Sci 2019; 1925-1932

275. Lavoie RA, Bouffard A, Meranger R, et al. Mercury transport and human exposure from global marine fisheries. Sci Rep 2018; 8(1):6705.

276. Rice GE, Hammitt JK, Evans JS. A probabilistic characterization of the health benefits of reducing methyl mercury intake in the United States. Environ Sci Technol 2010; 44(13):5216-24.

277. EFSA Scientific Committee. Statement on the benefits of fish/seafood consumption compared to the risks of methylmercury in fish/seafood. EFSA J 2015; 13(1):3982.

278. Ouedraogo O, Amyot M. Mercury, arsenic and selenium concentrations in water and fish from sub-Saharan semi-arid freshwater reservoirs (Burkina Faso). Sci Total Environ 2013; 444:243-254.

279. Ouedraogo O, Amyot M. Effects of various cooking methods and food components on bioaccessibility of mercury from fish. Environ Res 2011; 111(8):1064-1069.

280. Mansour SA. Monitoring and health risk assessment of heavy metal contamination in food. Practical food safety: contemporary issues and future directions. 2014; 19:235-55.

281. Renieri EA, Algakis AK, Kiriakakis M, et al. Cd, Pb and Hg biomonitoring in fish of the Mediterranean region and risk estimations on fish consumption. Toxics 2014; 2(3):417-42.

282. Oken E, Choi AL, Karagas MR, et al. Which fish should I eat? Perspectives influencing fish consumption choices. Environ Health Perspect 2012; 120(6):790-8.

283. Longvah T, Anantan I, Bhaskarachary K, et al. Indian food composition tables. National Institute of Nutrition 2017.

284. Verger P, Houdart S, Marette S, et al. Impact of a risk-benefit advisory on fish consumption and dietary exposure to methylmercury in France. Regul Toxicol Pharmacol 2007; 48(3):259-69.

285. Roosen J, Marette S, Blanchemanche S, et al. Does health information matter for modifying consumption? A field experiment measuring the impact of risk information on fish consumption. Appl Econ Perspect Policy 2009; 31(1):2-0.

286. Park S, Johnson MA. Awareness of fish advisories and mercury exposure in women of childbearing age. Nutr Rev 2006; 64(5):250-6.

287. Knobeloch L, Anderson HA, Imm P, et al. Fish consumption, advisory awareness, and hair mercury levels among women of childbearing age. Environ Res 2005; 97(2):220-7.

288. Bigham GN, Chan WR, Dekermenjian M, et al. Indoor concentrations of Hg vapor following various spill scenarios. Environ Forensics 2008; 9(2-3):187-96.

289. ATSDR, Mercury Quick Facts. Cleaning Up Mercury Spills in Your House. US DHHS 2009.

290. ATSDR NIOSH Guidelines. Workplace Safety and Health Topics. Mercury 2019.

291. Gochfeld M, Burger J, Jeitner C, et al. Seasonal, locational and size variations in mercury and selenium levels in striped bass (Morone saxatilis) from New Jersey. Environ Res 2012; 112:8-19.

292. Gochfeld M. Cases of mercury exposure, bioavailability, and absorption. Ecotoxicology and environmental safety 2003; 56(1):174-9.

293. Tewell M, Spoto S, Wiese M, et al. Mercury Poisoning at a Home Day Care Center—Hillsborough County, Florida, 2015. MMWR Morb Mortal Wkly Rep 2017; 66(17):433.

294. Johnson-Arbor K, Tefera E, Farrell Jr J. Characteristics and treatment of elemental mercury intoxication: A case series. Health Sci Rep 2021; 4(2):293.

295. Scheepers PT, van Ballegooij-Gevers M, Jans H. Biological monitoring involving children exposed to mercury from a barometer in a private residence. Toxicol Lett 2014; 231(3):365-73.

296. Aucott M, McLinden M, Winka M. Release of mercury from broken fluorescent bulbs. J Air Waste Manag Assoc 2014; 53(2):143-51.

297. EPA. How to Clean up a Small Mercury Spill. EPA, Washington, DC 2019.

298. Pacyna J, and Munthe J, EPA, Mercury Workshop presentation. Brussels, Belgium 2004

299. Xu J, Yan CH, Hu H, et al. Prenatal maternal occupational exposure and postnatal child exposure to elemental mercury. Pediatr Emerg Care 2016; 32(3):175-9.

300. Sinha S, Rao K, Rawat A. Forensic approach towards criminal use of mercury in domestic violence. Sri Lanka J Foren Med Sci Law 2023; 24-31.

301. Solis MT, Yuen E, Cortez PS, et al. Family poisoned by mercury vapor inhalation. Am J Emerg Med 2000; 18(5):599-602.

302. Moutinho ME, Tompkins AL, Rowland TW, et al. Acute mercury vapor poisoning: fatality in an infant. Am J Dis Child 1981; 135(1):42-4.

303. Lien DC, Todoruk DN, Rajani HR, et al. Accidental inhalation of mercury vapour: respiratory and toxicologic consequences. Can Med Assoc J 1983; 129(6):591.

304. Appel PW, Na-Oy LD. Mercury-free gold extraction using borax for small-scale gold miners. J Environ Prot 2014; 2014.

305. Riley DM, Newby CA, Leal-Almeraz TO, et al. Assessing elemental mercury vapor exposure from cultural and religious practices. Environ Health Perspect 2001; 109(8):779-84.

306. Schurz Rogers H, McCullough J, Kieszak S, et al. Exposure assessment of young children living in Chicago communities with historic reports of ritualistic use of mercury. Clin Toxicol (Phila) 2007;45(3):240-7.

307. Zhao M, Li Y, Wang Z. Mercury and mercury-containing preparations: History of use, clinical applications, pharmacology, toxicology, and pharmacokinetics in traditional Chinese medicine. Front Pharmacol 2022; 13:807807.

308. FDA, Thimerosal and Vaccines, and Mercury in Drugs and Biologic Products. FDA, Silver Spring, MD 2018.

309. Cherne K. Understanding mercury poisoning. Healthline. 2022.

310. EPA, How People are Exposed to Mercury. EPA 2022.

311. Murphy T, Lim S, Kim S, et al. Metal contamination in low-cost jewelry and toys in Cambodia. J Health Pollut 2016; 6(11):47-57.

312. Lewis J. Global Beauty Hazard: Assessing Mercury in Skin-Lightening Products. Environ Health Perspect 2023; 131(1):014002.

313. Bastiansz A, Ewald J, Rodríguez Saldaña V, et al. A systematic review of mercury exposures from skin-lightening products. Environ Health Perspect 2022; 130(11):116002.

314. Ori MR, Larsen JB. Mercury poisoning in a toddler from home contamination due to skin-lightening cream. J Pediatr 2018; 196:314-7.

315. Copan L, Fowles J, Barreau T, et al. Mercury toxicity and contamination of households from the use of skin creams adulterated with mercurous chloride (calomel). Int J Environ Res Public Health 2015; 12(9):10943-54.

316. McKelvey W, Jeffery N, Clark N, et al. Population-based inorganic mercury biomonitoring and the identification of skin care products as a source of exposure in New York City. Environ Health Perspect 2011; 119(2):203-9.

317. Brodziak-Dopierala B, Fischer A, Szczelina W, et al. The content of mercury in herbal dietary supplements. Biol Trace Elem Res 2018; 185:236-43.

318. Saper RB, Phillips RS, Sehgal A, et al. Lead, mercury, and arsenic in US-and Indian-manufactured Ayurvedic medicines sold *via* the Internet. JAMA 2008; 300(8):915-23.

319. Chopra A, Doiphode VV. Ayurvedic medicine: core concept, therapeutic principles, and current relevance. Med Clin North Am 2002; 86(1):75-89.

320. Dargan PI, Gawarammana IB, Archer JR, et al. Heavy metal poisoning from Ayurvedic traditional medicines: an emerging problem? Int J Environ Health 2008; 2(3-4):463-74.

321. Golding J, Steer CD, Hibbeln JR, et al. Dietary predictors of maternal prenatal blood mercury levels in the ALSPAC birth cohort study. Environ Health Perspect 2013; 121(10):1214-8.

322. Bakerink JA, Gospe Jr SM, Dimand RJ, et al. Multiple organ failure after ingestion of pennyroyal oil from herbal tea in two infants. Pediatrics 1996; 98(5):944-7.

323. NIOSH, Report to Congress on Worker's Home Contamination Study Conducted Under the Worker's Family Protection Act (29 U.S.C. 671a). 2014; 22-24.

324. Hudson PJ, Vogt RL, Brondum J, et al. Elemental mercury exposure among children of thermometer plant workers. Pediatrics 1987; 79(6):935-8.

325. Ismawati Y, Zaki K, Gita A, et al. Indoor air mercury monitoring in ten hospitals in Denpasar City, Bali, Indonesia. BaliFokus, Bali, Indonesia. 2013.

326. Dufault R, LeBlanc B, Schnoll R, et al. Mercury from chlor-alkali plants: measured concentrations in food product sugar. Environ Health 2009; 8(1):1-6.

327. Bravo AG, Cosio C, Amouroux D, et al. Extremely elevated methyl mercury levels in water, sediment and organisms in a Romanian reservoir affected by release of mercury from a chlor-alkali plant. Water Res 2014; 49:391-405.

328. Lenka M, Panda KK, Panda BB. Monitoring and assessment of mercury pollution in the vicinity of a chloralkali plant. IV. Bioconcentration of mercury in in situ aquatic and terrestrial plants at Ganjam, India. Arch Environ Contam Toxicol 1992; 22:195-202.

329. Esbri JM, López-Berdonces MA, Fernández-Calderón S, et al. Atmospheric mercury pollution around a chlor-alkali plant in Flix (NE Spain): An integrated analysis. Environ Sci Pollut Res Int 2015; 22:4842-50.

330. Montuori P, Jover E, Díez S, et al. Mercury speciation in the hair of pre-school children living near a chlor-alkali plant. Sci Total Environ 2006; 369(1-3):51-8.

331. Torrente M, Gascon M, Vrijheid M, et al. Levels of metals in hair in childhood: preliminary associations with neuropsychological behaviors. Toxics 2013; 2(1):1-6.

332. Reis AT, Rodrigues SM, Araujo C, et al. Mercury contamination in the vicinity of a chlor-alkali plant and potential risks to local population. Sci Total Environ 2009; 407(8):2689-700.

333. Gibicar D, Horvat M, Logar M, et al. Human exposure to mercury in the vicinity of chlor-alkali plant. Environ Res 2009; 109(4):355-67.

334. EPA, National Emissions Inventory, Version 2, Technical Support Document. Research Triangle Park, NC 2018; 2-23–2-31.

335. Karunasagar D, Krishna MB, Anjaneyulu YA, et al. Studies of mercury pollution in a lake due to a thermometer factory situated in a tourist resort: Kodaikkanal, India. Environ Pollut 2006; 143(1):153-8.

336. Tominack R, Weber J, Blume C, et al. Elemental mercury as an attractive nuisance: multiple exposures from a pilfered school supply with severe consequences. Pediatr Emerg Care 2002; 18(2):97-100.

337. EPA. Case studies of Mercury Contamination and Cleanup of Schools. EPA 2022.

338. Burgess JL. Editorial on "Exposure assessment of a mercury spill in a Nevada school—2004". Clin Toxicol (Phila) 2007; 45(4):431.

339. Gordon AT. Short-Term Elemental Mercury Exposures at Three Arizona Schools: Public Health Lessons Learned. J Toxicol Clin Toxicol 2004; 42(2):179-187.

340. Carman KB, Tutkun E, Yilmaz H, et al. Acute mercury poisoning among children in two provinces of Turkey. Eur J Pediatr 2013; 172:821-7.

341. Akyildiz BN, Kondolot M, Kurtoglu S, et al. Case series of mercury toxicity among children in a hot, closed environment. Pediatr Emerg Care 2012; 28(3):254-258.

342. Aslan L, Aslakurt M, Dilber C, et al. Ophthalmic Findings of Acute Mercury Poisoning in Primary School Students. J Clinic Toxicol S 2012; 1:2161-0495.

343. Ohio EPA, Mercury Awareness for School Teachers. Columbus 2001.

344. ATSDR, Action Levels for Elemental Mercury Spills. US DHHS, PHS, Atlanta, GA, 2012.

345. Kiddie Kollege. Mercury exposure investigation using serial urine testing and medical records review. Kiddie Kollege, ATSDR 2007.

346. Orloff KC, Uliksch G, Wilder L, et al. Human exposure to elemental mercury in a contaminated residential building. Arch Environ Health 1997; 52(3):169-72.

347. Lowry LK, Rountree PP, Levin JL, et al. The Texarkana mercury incident. Tex Med 1999; 95(10):65-70.

348. MacLehose R, Pitt G, Will S, et al. Mercury contamination incident. J Public Health Med 2001; 23(1):18-22.

349. George L, Scott FE, Cole D, et al. The mercury emergency and Hamilton school children: a follow-up analysis. Can J Public Health 1996; 87(4):224-6.

350. Tunnessen Jr WW, McMahon KJ, Baser M. Acrodynia: exposure to mercury from fluorescent light bulbs. Pediatrics 1987; 79(5):786-9.

351. ATSDR. West Grand Boulevard mercury spill. US DHHS, PHS, Atlanta, GA 2001.

352. Dummer TJ, Dickinson HO, Parker L. Adverse pregnancy outcomes around incinerators and crematoriums in Cumbria, north west England, 1956–93. J Epidemiol Community Health 2003; 57(6):456-61.

353. Yu JG, Yue BY, Wu XW, et al. Removal of mercury by adsorption: a review. Environ Sci Pollut Res Int 2016; 23:5056-76.

354. Reddy BM, Durgasri N, Kumar TV, et al. Abatement of gas-phase mercury—recent developments. Catal Rev 2012; 54(3):344-98.

355. Streets DG, Lu Z, Levin L, et al. Historical releases of mercury to air, land, and water from coal combustion. Sci Total Environ 2018; 615:131-40.

356. Lipfert F, Morris S, Sullivan T, et al. Methylmercury, fish consumption, and the precautionary principle. J Air Waste Manag Assoc 2005; 55(4):388-98.

357. Sullivan TM, Bowerman B, Adams J, et al. The Local Impacts of Mercury Emissions from Coal Fired Power Plants on Human Health Risk, Progress Report for the Period of March 2003, Brookhaven National Laboratory, Upton, NY, 2003.

358. Sullivan TM, Bowerman B, Adams J, et al. Local Impacts of Mercury Emissions from Coal Fired Power Plants. Brookhaven National Laboratory, Upton, NY., 2005.

359. George J, Masto RE, Ram LC, et al. Human exposure risks for metals in soil near a coal-fired power-generating plant. Arch Environ Contam Toxicol 2015; 68:451-61.

360. Sackett DK, Aday DD, Rice JA, et al. Does proximity to coal-fired power plants influence fish tissue mercury? Ecotoxicology 2010; 19:1601-11.

361. Tang D, Li TY, Liu JJ, et al. Effects of prenatal exposure to coal-burning pollutants on children's development in China. Environ Health Perspect 2008; 116(5):674-9.

362. Mukherjee AB, Bhattacharya P, Sarkar A, et al. Mercury emissions from industrial sources in India and its effects in the environment. Springer 2009; 81-112.

363. Edwards P. Global cement emissions standards. Global Cement Magazine 2014. 25-34.

364. Di Ciaula A. Bioaccumulation of toxic metals in children exposed to urban pollution and to cement plant emissions. Expo Health 2021; 13(4):681-95.

365. Lederman SA, Jones RL, Caldwell KL, et al. Relation between cord blood mercury levels and early child development in a World Trade Center cohort. Environ Health Perspect 2008; 116(8):1085-91.

366. Malm O. Gold mining as a source of mercury exposure in the Brazilian Amazon. Environ Res 1998; 77(2):73-8.

367. Nandiyanto AB, Raghadhita R, Al Husaeni DN, et al. Research trend on the use of mercury in gold mining: Literature review and bibliometric analysis. Moroc J Chem 2023; 11(1):11.

368. Gibb H, O'Leary KG. Mercury exposure and health impacts among individuals in the artisanal and small-scale gold mining community: a comprehensive review. Environ Health Perspect 2014; 122(7):667-72.

369. dos Santos-Lima C, de Souza Mourão D, de Carvalho CF, et al. Neuropsychological effects of mercury exposure in children and adolescents of the Amazon Region, Brazil. Neurotoxicology 2020; 79:48-57.

370. de Oliveira DF, Bastos WR, Castro BS, et al. Risk assessment to the health of amazonian indigenous for the consumption of fish, meat of hunts and vegetables containing metylmercury. Int J Adv Eng Res Sci 2018; 5(9):264281.

371. Pinheiro MC, Crespo-López ME, Vieira JL, et al. Mercury pollution and childhood in Amazon riverside villages. Environ Int 2007; 33(1):56-61.

372. Grandjean P, White RF, Nielsen A, et al. Methylmercury neurotoxicity in Amazonian children downstream from gold mining. Environ Health Perspect 1999; 107(7):587-91.

373. de Oliveira Corvelo TC, Oliveira EA, de Parijos AM, et al. Monitoring mercury exposure in reproductive aged women inhabiting the Tapajos River basin, Amazon. Bull Environ Contam Toxicol 2014; 93:42-6.

374. Torres FG, De-la-Torre GE. Mercury pollution in Peru: geographic distribution, health hazards, and sustainable removal technologies. Environ Sci Pollut Res Int 2022; 29(36):54045-59.

375. Niane B, Guedron S, Moritz R, et al. Human exposure to mercury in artisanal small-scale gold mining areas of Kedougou region, Senegal, as a function of occupational activity and fish consumption. Environ Sci Pollut Res Int 2015; 22:7101-11.

376. de Freitas Fonseca M, Hacon SD, Grandjean P, et al. Iron status as a covariate in methylmercury-associated neurotoxicity risk. Chemosphere 2014; 100:89-96.

377. Mason RP, Baumann Z, Hansen G, et al. An assessment of the impact of artisanal and commercial gold mining on mercury and methylmercury levels in the environment and fish in Cote d'Ivoire. Sci Total Environ 2019; 665:1158-67.

378. Acosta-Saavedra LC, Moreno ME, Rodríguez-Kessler T, et al. Environmental exposure to lead and mercury in Mexican children: a real health problem. Toxicol Mech Methods 2011; 21(9):656-66.

379. Du B, Li P, Feng X, et al. Mercury exposure in children of the Wanshan mercury mining area, Guizhou, China. Int J Environ Res Public Health 2016; 13(11):1107.

380. Díez S, Esbri JM, Tobias A, et al. Determinants of exposure to mercury in hair from inhabitants of the largest mercury mine in the world. Chemosphere 2011; 84(5):571-7.

381. Molin C. Amalgam–fact and fiction. Scand J Dent Res 1992; 100(1):66-73.

382. Cooley RL, Stilley J, Lubow RM. Mercury vapor produced

during sterilization of amalgam-contaminated instruments. J Prosthet Dent 1985; 53(3):304-8.

383. Univ. of Mass. Occupational Exposure to Elemental Mercury in Odontology/Dentistry. University of Massachusetts, MA 2012.

384. Duncan A, O'Reilly DS, McDonald EB, et al. Thirty-five year review of a mercury monitoring service for Scottish dental practices. Br Dent J 2011; 210(3): E2.

385. Naimi-Akbar A, Sandborgh-Englund G, Ekbom A, et al. Cognitive function among sons of women who worked in dentistry. Scand J Work Environ Health 2012; 546-52.

386. Heggland I, Irgens A, Tollanes M, et al. Pregnancy outcomes among female dental personnel—a registry-based retrospective cohort study. Scand J Work Environ Health 2011; 539-46.

387. Sandborgh-Englund G, Elinder CG, Johanson G, et al. The absorption, blood levels, and excretion of mercury after a single dose of mercury vapor in humans. Toxicol Appl Pharmacol 1998; 150(1):146-53.

388. Guzzi G, Minoia C, Pigatto PD, et al. Methylmercury, amalgams, and children's health. Environ Health Perspect 2006; 114(3):A149.

389. Kingman A, Albertini T, Brown LJ. Mercury concentrations in urine and whole blood associated with amalgam exposure in a US military population. J Dent Res 1998; 77(3):461-71.

390. FDA. Information for Patients About Dental Amalgam Fillings. FDA, Silver Spring 2020.

391. Watson GE, van Wijngaarden E, Love TM, et al. Neurodevelopmental outcomes at 5 years in children exposed prenatally to maternal dental amalgam: the Seychelles Child Development Nutrition Study. Neurotoxicol Teratol 2013; 39:57-62.

392. Palkovicova L, Ursinyova M, Masanova V, et al. Maternal amalgam dental fillings as the source of mercury exposure in developing fetus and newborn. J Expo Sci Environ Epidemiol 2008; 18(3):326-31.

393. Vieira SM, de Almeida R, Holanda IB, et al. Total and methyl-mercury in hair and milk of mothers living in the city of Porto Velho and in villages along the Rio Madeira, Amazon, Brazil. Int J Hyg Environ Health 2013; 216(6):682-9.

394. Björkman L, Lygre GB, Haug K, et al. Perinatal death and exposure to dental amalgam fillings during pregnancy in the population-based MoBa cohort. PLoS One 2018; 13(12): Article No 0208803.

395. Levy M, Schwartz S, Dijak M, et al. Childhood urine mercury excretion: dental amalgam and fish consumption as exposure factors. Environ Res 2004; 94(3):283-90.

396. Surkan PJ, Wypij D, Trachtenberg F, et al. Neuropsychological function in school-age children with low mercury exposures. Environ Res 2009; 109(6):728-33.

397. Bellinger DC, Daniel D, Trachtenberg F, et al. Dental amalgam restorations and children's neuropsychological function: the New England Children's Amalgam Trial. Environ Health Perspect 2007; 115(3):440-6.

398. DeRouen TA, Martin MD, Leroux BG, et al. Neurobehavioral effects of dental amalgam in children: a randomized clinical trial. JAMA 2006; 295(15):1784-92.

399. Dunn JE, Trachtenberg FL, Barregard L, et al. Scalp hair and urine mercury content of children in the Northeast United States: the New England Children's Amalgam Trial. Environ Res 2008; 107(1):79-88.

400. Uçar Y, Brantley W. Biocompatibility of dental amalgams. Int J Dent 2017; 95-111.

401. Gil-Hernández F, Gómez-Fernández AR, la Torre-Aguilar MJ, et al. Neurotoxicity by mercury is not associated with autism spectrum disorders in Spanish children. Ital J Pediatr 2020; 46(1):1-7.

402. Kaur I, Behl T, Aleya Let al. Role of metallic pollutants in neurodegeneration: effects of aluminum, lead, mercury, and arsenic in mediating brain impairment events and autism spectrum disorder. Environ Sci Pollut Res Int 2021; 28:8989-9001.

403. Morris G, Puri BK, Frye RE, et al. The putative role of environmental mercury in the pathogenesis and pathophysiology of autism spectrum disorders and subtypes. Mol Neurobiol 2018; 55:4834-56.

404. Kern JK, Geier DA, Sykes LK, et al. The relationship between mercury and autism: A comprehensive review and discussion. J Trace Elem Med Biol 2016; 37:8-24.

405. ADA, Amalgam, American Dental Association online update 2021.

406. Takahashi Y, Yoshida M. Effects of mercury vapor released from dental amalgam on health and environment. St Marianna Med J 2002; 30:1-0.

407. Mulligan S, Kakonyi G, Moharamzadeh K, et al. The environmental impact of dental amalgam and resin-based composite materials. Br Dent J 2018; 224(7):542-8.

408. Homme KG, Kern JK, Haley BE, et al. New science challenges old notion that mercury dental amalgam is safe. Biometals 2014; 27:19-24.

409. Oliveira BH, Rajendra A, Veitz-Keenan A, et al. The effect of silver diamine fluoride in preventing caries in the primary dentition: a systematic review and meta-analysis. Caries Res 2019; 53(1):24-32.

410. Vahter M, Åkesson A, Lind B, et al. Longitudinal study of methylmercury and inorganic mercury in blood and urine of pregnant and lactating women, as well as in umbilical cord blood. Environ Res 2000; 84(2):186-94.

411. Pirard C, Koppen G, De Cremer K, et al. Hair mercury and urinary cadmium levels in Belgian children and their mothers within the framework of the COPHES/DEMOCOPHES projects. Sci Total Environ 2014; 472:730-40.

412. Bárány E, Bergdahl IA, Bratteby LE, et al. Mercury and selenium in whole blood and serum in relation to fish consumption and amalgam fillings in adolescents. J Trace

Elem Med Biol 2003; 17(3):165-70.

413. Golding J, Hibbeln JR, Gregory SM, et al. Maternal prenatal blood mercury is not adversely associated with offspring IQ at 8 years provided the mother eats fish: a British prebirth cohort study. Int J Hyg Environ Health 2017; 220(7):1161-7.

414. Li J, Tian X, Zhao J, et al. Temporal changes of blood mercury concentrations in Chinese newborns and the general public from 1980s to 2020 s. J Trace Elem Med Biol 2023; 127126.

415. Fu X, Feng X, Sommar J, et al. A review of studies on atmospheric mercury in China. Sci Total Environ 2012; 421:73-81.

416. Jurewicz J, Polanska K, Hanke W. Chemical exposure early in life and the neurodevelopment of children–an overview of current epidemiological evidence. Ann Agric Environ Med 2013; 20(3).

417. Dorea JG, Marques RC, Isejima C. Neurodevelopment of Amazonian infants: antenatal and postnatal exposure to methyl-and ethylmercury. J Biomed Biotechnol 2012; 2012.

418. Nuttall KL. Interpreting mercury in blood and urine of individual patients. Ann Clin Lab Sci 2004; 34(3):235-50.

419. Murata K, Weihe P, Renzoni A, et al. Delayed evoked potentials in children exposed to methylmercury from seafood. Neurotoxicol Teratol 1999; 21(4):343-8.

420. Broussard LA, Hammett-Stabler CA, Winecker RE, et al. The toxicology of mercury. Lab Med 2002; 33(8):614-25.

421. El-Sherbeeny AM, Odom JV, Smith JE. Visual system manifestations due to systemic exposure to mercury. Cutan Ocul Toxicol 2006; 25(3):173-83.

422. Johansson C, Castoldi AF, Onishchenko N, et al. Neurobehavioral and molecular changes induced by methylmercury exposure during development. Neurotox Res 2007; 11:241-60.

423. Risher JF, Murray HE, Prince GR. Organic mercury compounds: human exposure and its relevance to public health. Toxicol Ind Health 2002; 18(3):109-60.

424. Nagi NA, Yassin AK. Organic mercury poisoning in children. J Trop Med Hyg 1974; 77(6):128-32.

425. Jao-Tan C, Pope E. Cutaneous poisoning syndromes in children: a review. Curr Opin Pediatr 2006; 18(4):410-6.

426. Vianna AD, Matos EP, Jesus IM, et al. Human exposure to mercury and its hematological effects: a systematic review. Cad Saude Publica 2019; 35.

427. Sadlik JK. A chemico-toxicological expert report concerning metallic mercury. Foren Sci Prob 2007; LXX:236-244.

428. Eto K, Takizawa Y, Akagi H, et al. Differential diagnosis between organic and inorganic mercury poisoning in human cases-the pathologic point of view. Toxicol Pathol 1999; 27(6):664-71.

429. Hidayat R, Amqam H, Amiruddin RP, et al. Relationship of Fish Consumption to Hair Mercury Levels of Pregnant Women. Saudi J Biomed Res.

430. Salcedo-Bellido I, Gutiérrez-González E, García-Esquinas E, et al. Toxic metals in toenails as biomarkers of exposure: A review. Environ Res 2021; 197:111028.

431. Branco V, Caito S, Farina M, et al. Biomarkers of mercury toxicity: Past, present, and future trends. J Toxicol Environ Health B Crit Rev 2017; 20(3):119-54.

432. Schaefer AM, Jensen EL, Bossart GD, et al. Hair mercury concentrations and fish consumption patterns in Florida residents. Int J Environ Res Public Health 2014; 11(7):6709-26.

433. Miklavčič A, Cudreman P, Mazej D, et al. Biomarkers of low-level mercury exposure through fish consumption in pregnant and lactating Slovenian women. Environ Res2011; 111(8):1201-7.

434. Marques RC, Dorea JG, Bastos WR, et al. Changes in children hair-Hg concentrations during the first 5 years: maternal, environmental and iatrogenic modifying factors. Regul Toxicol Pharmacol 2007; 49(1):17-24.

435. Passos CJ, Mergler D, Lemire M, et al. Fish consumption and bioindicators of inorganic mercury exposure. Sci Total Environ 2007; 373(1):68-76.

436. Chen G, Chen X, Yan C, et al. Surveying mercury levels in hair, blood and urine of under 7-year old children from a coastal city in China. Int J Environ Res Public Health 2014; 11(11):12029-41.

437. World Health Organization. Biological monitoring of chemical exposure in the workplace: guidelines. World Health Organization 1996.

438. Legrand M, Feeley M, Tikhonov C, et al. Methylmercury blood guidance values for Canada. Can J Public Health 2010; 101:28-31.

439. Carneiro MF, Grotto D, Barbosa Jr F. Inorganic and methylmercury levels in plasma are differentially associated with age, gender, and oxidative stress markers in a population exposed to mercury through fish consumption. J Toxicol Environ Health A 2014; 77(1-3):69-79.

440. Tsuchiya A, Duff R, Stern AH, et al. Single blood-Hg samples can result in exposure misclassification: temporal monitoring within the Japanese community (United States). Environ Health 2012; 11:1-8.

441. Genuis SJ, Birkholz D, Rodushkin I, et al. Blood, urine, and sweat (BUS) study: monitoring and elimination of bioaccumulated toxic elements. Arch Environ Contam Toxicol 2011; 61:344-57.

442. Sears ME, Kerr KJ, Bray RI. Arsenic, cadmium, lead, and mercury in sweat: a systematic review. J Environ Public Health 2012; 2012.

443. Lovejoy HB, Bell Jr ZG, Vizena TR. Mercury exposure evaluations and their correlation with urine mercury excretions: 4. Elimination of mercury by sweating. J Occup Med 1973; 15(7):590-1.

444. Rees JR, Sturup S, Chen C, et al. Toenail mercury and dietary

fish consumption. J Expo Sci Environ Epidemiol 2007; 17(1):25-30.

445. Seppänen K, Kantola M, Laatikainen R, et al. Effect of supplementation with organic selenium on mercury status as measured by mercury in pubic hair. J Trace Elem Med Biol 2000; 14(2):84-7.

446. Airey D. Mercury in human hair due to environment and diet: a review. Environ Health Perspect 1983; 52:303-16.

447. Pesch A, Wilhelm M, Rostek U, et al. Mercury concentrations in urine, scalp hair, and saliva in children from Germany. J Expo Anal Environ Epidemiol 2002; 12(4):252-8.

448. Nyland JF, Fillion M, Barbosa Jr F, et al. Biomarkers of methylmercury exposure immunotoxicity among fish consumers in Amazonian Brazil. Environ Health Perspect 2011; 119(12):1733-8.

449. Gardner RM, Nyland JF, Silva IA, et al. Mercury exposure, serum antinuclear/antinucleolar antibodies, and serum cytokine levels in mining populations in Amazonian Brazil: a cross-sectional study. Environ Res 2010; 110(4):345-54.

450. Schoeters GE, Den Hond E, Koppen G, et al. Biomonitoring and biomarkers to unravel the risks from prenatal environmental exposures for later health outcomes. Am J Clin Nutr 2011; 94:1964S-9S.

451. Henshel D, Aschner M, Basu N, et al. Roundtable discussion groups summary papers: new bioindicators for mercury toxicological assessment: recommendations from the First International Bioindicators Roundtable Environ Bioindicat 2007; 2(3):183-207.

452. CDC, Biomonitoring Summary: Mercury. CDC, Atlanta, GA 2017.

453. EPA, Biomonitoring - Mercury. America's Children and the Environment, EPA 2022.

454. Astolfi ML, Conti ME, Ristorini M, et al. An analytical method for the biomonitoring of mercury in bees and beehive products by cold vapor atomic fluorescence spectrometry. Molecules 2021; 26(16):4878.

455. Scoffin K. Mercury Analyzers in the Laboratory. AMERICAN LABORATORY 2013; 45(4):20.

456. Zahir F, Rizwi SJ, Haq SK, et al. Low dose mercury toxicity and human health. Environ Toxicol Pharmacol 2005; 20(2):351-60.

457. Guidotti TL, McNamara J, Moses MS. The interpretation of trace element analysis in body fluids. Indian J Med Res 2008; 128(4):524-32.

458. Tezer H, Kaya A, Kalkan G, et al. Mercury poisoning: a diagnostic challenge. Pediatr Emerg Care 2012; 28(11):1236-7.

459. Rafati-Rahimzadeh M, Rafati-Rahimzadeh M, Kazemi S, et al. Current approaches of the management of mercury poisoning: need of the hour. Daru 2014; 22:1-0.

460. Rusniak DE, Arroyo A, Acciani J, et al. Heavy metal poisoning: management of intoxication and antidotes. EXS 2010; 365-96.

461. Mutter J, Yeter D. Kawasaki's disease, acrodynia, and mercury. Curr Med Chem 2008; 15(28):3000-10.

462. Khodashenas E, Aelami M, Balali-Mood M. Mercury poisoning in two 13-year-old twin sisters. J Res Med Sci 2015; 20(3):308.

463. Spiller HA, Hays HL, Casavant MJ. Rethinking treatment of mercury poisoning: The roles of selenium, acetylcysteine, and thiol chelators in the treatment of mercury poisoning: A narrative review. Toxicol Commun 2021; 5(1):19-59.

464. Risher JF, Amler SN. Mercury exposure: evaluation and intervention: the inappropriate use of chelating agents in the diagnosis and treatment of putative mercury poisoning. Neurotoxicology 2005; 26(4):691-9.

465. Asano S, Eto K, Kurosaki E, et al. Acute inorganic mercury vapor inhalation poisoning. Pathol Int 2000; 50(3):169-74.

466. Sarikaya S, Karcioglu O, Ay D, et al. Acute mercury poisoning: a case report. BMC Emerg Med 2010; 10(1):1-3.

467. Gao Z, Ying X, Yan J, et al. Acute mercury vapor poisoning in a 3-month-old infant: A case report. Clin Chim Acta 2017; 465:119-22.

468. Polańska K, Jurewicz J, Hanke W. Review of current evidence on the impact of pesticides, polychlorinated biphenyls and selected metals on attention deficit/hyperactivity disorder in children. Int J Occup Med Environ Health 2013; 26:16-38.

469. Chrysochoou C, Rutishauser C, Rauber-Lüthy C, et al. An 11-month-old boy with psychomotor regression and auto-aggressive behavior. Eur J Pediatr 2003; 162:559-61.

470. Rennie AC, McGregor-Schuerman M, Dale IM, et al. Mercury poisoning after spillage at home from a sphygmomanometer on loan from hospital. BMJ 1999; 319(7206):366-7.

471. Satoh H. Occupational and environmental toxicology of mercury and its compounds. Ind Health 2000; 38(2):153-64.

472. Centers for Disease Control (CDC. Acute and chronic poisoning from residential exposures to elemental mercury--Michigan, 1989-1990. MMWR Morb Mortal Wkly Rep 1991; 40(23):393-5.

473. Abbaslou P, Zaman T. A child with elemental mercury poisoning and unusual brain MRI findings. Clin Toxicol (Phila) 2006; 44(1):85-8.

474. Caravati EM, Erdman AR, Christianson G, et al. Elemental mercury exposure: an evidence-based consensus guideline for out-of-hospital management. Clin Toxicol (Phila) 2008; 46(1):1-21.

475. Dorea JG, Farina M, Rocha JB. Toxicity of ethylmercury (and Thimerosal): a comparison with methylmercury. J Appl Toxicol 2013; 33(8):700-11.

476. Yorifugi T, Murata K, Bjerve KS, et al. Visual evoked potentials in children prenatally exposed to methylmercury. Neurotoxicology 2013; 37:15-8.

477. Karagas MR, Choi AL, Oken E, et al. Evidence on the human health effects of low-level methylmercury exposure. Environ Health Perspect 2012; 120(6):799-806.

478. Grandjean P, Weihe P, White RF, et al. Cognitive deficit in 7-year-old children with prenatal exposure to methylmercury. Neurotoxicol Teratol 1997; 19(6):417-28.

479. Wigle DT, Arbuckle TE, Turner MC, et al. Epidemiologic evidence of relationships between reproductive and child health outcomes and environmental chemical contaminants. J Toxicol Environ Health B Crit Rev 2008; 11(5-6):373-517.

480. Endo T, Haraguchi K. High mercury levels in hair samples from residents of Taiji, a Japanese whaling town. Mar Pollut Bull 2010; 60(5):743-7.

481. Quintana H, Butterbaugh GJ, Purnell W, et al. Fluoxetine monotherapy in attention-deficit/hyperactivity disorder and comorbid non-bipolar mood disorders in children and adolescents. Child Psychiatry Hum Dev 2007; 37:241-53.

482. Amin-Zaki L, Majeed MA, Clarkson TW, et al. Methylmercury poisoning in Iraqi children: clinical observations over two years. Br Med J 1978; 1(6113):613-6.

483. Taber KH, Hurley RA. Mercury exposure: effects across the lifespan. J Neuropsychiatry Clin Neurosci 2008; 20(4): iv-389.

484. Davis LE, Kornfeld M, Mooney HS, et al. Methylmercury poisoning: Long-term clinical, radiological, toxicological, and pathological studies of an affected family. Ann Neurol 1994; 35(6):680-8.

485. Silbernagel SM, Carpenter DO, Gilbert SG, et al. Recognizing and preventing overexposure to methylmercury from fish and seafood consumption: information for physicians. J Toxicol 2011; 2011.

486. Nachman KE, Fox MA, Sheehan MC, et al. Leveraging epidemiology to improve risk assessment. Open Epidemiol J 2011; 4:3.

487. S. Boyles, Mercury levels in vaccines are safe, WebMD, Dec 3, 2002.

488. Marques RC, Dorea JG, Fonseca MF, et al. Hair mercury in breast-fed infants exposed to thimerosal-preserved vaccines. Eur J Pediatr 2007; 166:935-41.

489. Magos L. Review on the toxicity of ethylmercury including its presence as a preservative in biological and pharmaceutical products. J Appl Toxicol 2001; 21(1):1-5.

490. NIH, Phenyl Mercuric Acetate. Pub Chem, National Library of Medicine Bethesda, MD 2020.

491. Gotelli CA, Astolfi E, Cox C, et al. Early biochemical effects of an organic mercury fungicide on infants:" dose makes the poison". Science. 1985; 227(4687):638-40.

492. Seiler HG, Sigel H, Sigel A. Handbook on toxicity of inorganic compounds. 1988.

493. FDA, Mercury Poisoning Linked to Skin Products. FDA, Silver Springs 2016.

494. Cappelletti S, Piacentino D, Fineschi V, et al. Mercuric chloride poisoning: symptoms, analysis, therapies, and autoptic findings. A review of the literature. Crit Rev Toxicol 2019; 49(4):329-41.

495. Ashkenazi I, Desatnik HR, Abraham FA. Yellow mercuric oxide: a treatment of choice for *phthiriasis palpebrarum*. Br J Ophthalmol. 1991 ;75(6):356-8.

496. De Bont B, Lauwerys R, Govaerts H, et al. Yellow mercuric oxide ointment and mercury intoxication. Eur J Pediatr1986; 145:217-218.

497. EPA, Mercury Use in Batteries. IMERC Fact Sheet – 2015, EPA, Washington, DC 2015.

498. Centers for Disease Control and Prevention. Injuries from batteries among children aged. MMWR Morb Mortal Wkly Rep 2012 ; 61(34):661-6.

499. Davidson PW, Strain JJ, Myers GJ, et al. Neurodevelopmental effects of maternal nutritional status and exposure to methylmercury from eating fish during pregnancy. Neurotoxicology 2008; 29(5):767-75.

500. Timmerman R, Omaye ST. Selenium's utility in mercury toxicity: a mini-review. Food Sci Nutr 2021; 12(2):124-37.

501. Jadán-Piedra C, Chiocchetti GM, Clemente MJ, et al. Dietary compounds as modulators of metals and metalloids toxicity. Crit Rev Food Sci Nutr 2018; 58(12):2055-67.

502. Canuel R, de Grosbois SB, Lucotte M, et al. New evidence on the effects of tea on mercury metabolism in humans. Arch Environ Occup Health 2006; 61(5):232-8.

503. Castoldi AF, Johansson C, Onishchenko N, et al. Human developmental neurotoxicity of methylmercury: impact of variables and risk modifiers. Regul Toxicol Pharmacol 2008; 51(2):201-14.

504. Passos CJ, Mergler D, Gaspar E, et al. Eating tropical fruit reduces mercury exposure from fish consumption in the Brazilian Amazon. Environ Res 2003; 93(2):123-30.

505. Passos CJ, Mergler D, Fillion M, et al. Epidemiologic confirmation that fruit consumption influences mercury exposure in riparian communities in the Brazilian Amazon. Environ Res 2007; 105(2):183-93.

506. Goyer RA. Nutrition and metal toxicity. Am J Clin Nutr 1995; 61(3):S646-50.

507. Wyatt L, Permar SR, Ortiz E, et al. Mercury exposure and poor nutritional status reduce response to six expanded program on immunization vaccines in children: an observational cohort study of communities affected by gold mining in the Peruvian Amazon. Int J Environ Res Public Health 2019 Feb;16(4):638.

508. Ralston NV, Raymond LJ. Dietary selenium's protective effects against methylmercury toxicity. Toxicology 2010; 278(1):112-23.

509. Yang DY, Chen YW, Gunn JM, et al. Selenium and mercury in organisms: interactions and mechanisms. Environ Rev 2008; 16(NA):71-92.

510. Choi AL, Budtz-Jørgensen E, Jørgensen PJ, et al. Selenium as a potential protective factor against mercury developmental neurotoxicity. Environ Res 2008; 107(1):45-52.

511. Pinheiro MD, Luiz Martins do Nascimento J, Carlos de Lima Silveira L, et al. Mercury and selenium–a review on aspects related to the health of human populations in the Amazon.

Environ Bioindic 2009; 4(3):222-45.

512. Lemire M, Mergler D, Fillion M, et al. Elevated blood selenium levels in the Brazilian Amazon. Sci Total Environ 2006; 366(1):101-11.

513. da Silva DS, Lucotte M, Paquet S, et al. Inverse mercury and selenium concentration patterns between herbivorous and piscivorous fish in the Tapajos River, Brazilian Amazon. Ecotoxicol Environ Saf 2013; 97:17-25.

514. Lemire M, Fillion M, Barbosa Jr F, et al. Elevated levels of selenium in the typical diet of Amazonian riverside populations. Sci Total Environ 2010; 408(19):4076-84.

515. Lemire M, Fillion M, Frenette B, et al. Selenium and mercury in the Brazilian Amazon: opposing influences on age-related cataracts. Environ Health Perspect 2010; 118(11):1584-9.

516. Raymond LJ, Ralston NV. Mercury: selenium interactions and health implications. Neurotoxicology 2020; 81:294-9.

517. Kehrig HA, Seixas TG, Di Beneditto AP, et al. Selenium and mercury in widely consumed seafood from South Atlantic Ocean. Ecotoxicol Environ Saf 2013; 93:156-62.

518. Squadrone S, Benedetto A, Brizio P, et al. Mercury and selenium in European catfish (*Silurus glanis*) from Northern Italian Rivers: can molar ratio be a predictive factor for mercury toxicity in a top predator? Chemosphere 2015; 119:24-30.

519. Cáceres-Saez I, Dellabianca NA, Goodall RN, et al. Mercury and selenium in subantarctic Commerson's dolphins (*Cephalorhynchus c. commersonii*). Biol Trace Elem Res 2013; 151:195-208.

520. Savery LC, Evers DC, Wise SS, et al. Global mercury and selenium concentrations in skin from free-ranging sperm whales (*Physeter macrocephalus*). Sci Total Environ 2013; 450:59-71.

521. Burger J, Gochfeld M, Jeitner C, et al. Selenium: mercury molar ratios in freshwater fish from Tennessee: individual, species, and geographical variations have implications for management. Ecohealth 2012; 9:171-82.

522. Berges-Tiznado ME, Márquez-Farias F, Lara-Mendoza RE, et al. Mercury and selenium in muscle and target organs of scalloped hammerhead sharks *Sphyrna lewini* of the SE Gulf of California: dietary intake, molar ratios, loads, and human health risks. Arch Environ Contam Toxicol 2015; 69:440-52.

523. Liu J, Portnoy J, Um P, et al. Blood lead and mercury levels are associated with low resting heart rate in community adolescent boys. Int J Hyg Environ Health 2021; 233:113685.

524. Dennehy C. Omega-3 fatty acids and ginger in maternal health: Pharmacology, efficacy, and safety. J Midwifery Women's Health 2011; 56(6):584-90.

525. Bridges CC, Zalups RK. Transport of inorganic mercury and methylmercury in target tissues and organs. J Toxicol Environ Health B Crit Rev 2010; 13(5):385-410.

526. do Nascimento JL, Oliveira KR, Crespo-Lopez ME, et al. Methylmercury neurotoxicity & antioxidant defenses. Indian J Med Res 2008; 128(4):373-82.

527. Barcelos GR, Grotto D, Serpeloni JM, et al. Bixin and norbixin protect against DNA-damage and alterations of redox status induced by methylmercury exposure in vivo. Environ Mol Mutagen 2012; 53(7):535-41.

528. Hursh JB, Greenwood MR, Clarkson TW, et al. The effect of ethanol on the fate of mercury vapor inhaled by man. J Pharmacol Exp Ther 1980; 214(3):520-7.

529. Kudsk FN. Absorption of mercury vapour from the respiratory tract in man. Acta Pharmacol Toxicol (Copenh) 1965; 23(2-3):250-62.

530. Martin MD, Naleway C. The inhibition of mercury absorption by dietary ethanol in humans: cross-sectional and case-control studies. Occup Environ Med 2004; 61(2):8.

531. Dufault R, Berg Z, Crider R, et al. Blood inorganic mercury is directly associated with glucose levels in the human population and may be linked to processed food intake. Integr Mol Med 2015; 2(3).

532. Wisconsin Dept. Mercury Ban in K-12 Schools. Wisconsin Dept Nat. Resources 2012.

533. Attwater M. A solution for mercury pollution? Nat Rev Microbiol 2023; 21(2):67.

534. Wu C, Tang D, Dai J, et al. Bioremediation of mercury-polluted soil and water by the plant symbiotic fungus *Metarhizium robertsii*. Proc Natl Acad Sci U S A 2022; 119(47): Article No 2214513119.

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