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Reviewing the different types of heavy materials in the human teeth*

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Abstract

Heavy materials can be detected by recording long-term exposures to human teeth due to their stable nature. Teeth have mechanical properties such as hardness, elasticity, viscoelasticity and fracture behaviour. In this review, the level of cadmium, lead, mercury, arsenic and etc. in human dental tissues was evaluated. In order to quantify these materials in teeth, various analytical techniques were used. The results indicated detectable levels of these heavy materials which varied between individuals and locations. Furthermore, there was a correlation between dietary habits, tooth type, age, gender, occupational exposures, and dental heavy material concentrations. Health implications of chronic exposure to heavy materials are highlighted by the findings, which emphasizes the importance of monitoring and mitigation of environmental sources.

Keywords: primary teeth; heavy materials; tooth types; age

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Introduction

Earth's crust contains a wide variety of natural materials, and their contents can vary from region to region. As a result, background concentrations of these materials can vary greatly from one region to another. Environmental factors and material properties govern how materials are distributed in the environment (1, 2). Many countries have experienced environmental contamination due to heavy materials for several decades. A human exposure to these materials can lead to adverse health effects, particularly in teenagers (3). Aside from this, children may be exposed to materials through contaminated soil when they walk or crawl, or even through some of the toys they play with (4). Children are exposed to a variety of neurotoxicants from bombs and bullets in war zones. According to current research, birth defects and cancer rates are increasing as a result of war-created pollution (5).

The environment is widely dispersed with lead, arsenic, mercury and cadmium. Humans do not benefit from these elements, and a homeostasis mechanism does not exist for them. Even at low concentrations, they can cause adverse health effects in humans and animals. Thus, they can damage cellular material and alters cellular genetics. However, zinc plays a critical role in the human body, and deficiency or excess can be detrimental (6). It is possible for heavy materials to find their way into teeth in a variety of ways. A variety of factors can contribute to the accumulation of these materials in dental tissues, including exposure to contaminated water resources, certain foods, and even prenatal exposure. The deposits of these materials could cause potential health risks if they become embedded in the tooth structure over time (7). There is a high degree of shielding from environmental assaults found in teeth, and they are an excellent source of DNA, extensive genetic diversity can be found in different parts of the teeth (8). The content of heavy materials in human teeth has also been assessed as a bio-indicator of environmental pollution. Because dental hard tissues are relatively stable, minerals deposited in teeth during mineralization are largely preserved. Thus, heavy material exposure during early life can be determined by primary teeth (9).

The effect of heavy materials in teeth is a topic that continues to garner scientific interest and debate. Many researches aim to determine the extent of heavy material accumulation in teeth and its potential health consequences, as well as effective strategies for preventing and mitigating them. An analysis of human teeth utilising laser induced breakdown spectroscopy (LIBS) was presented by Suyanto et al (10). they was found that Indonesian human teeth contain F, P, Si, Ca, Zn, Sn, Ar, Na, Li, Fe, K, Ti, Cr, Al, Mn and Ce. Nazemisalman et al. (11) showed that the amount of heavy metal pollution in Zanjan Province, Iran, by measuring the levels of Pb, Cd, Zn and Cu in children's teeth which they were found at mean concentrations of 7.66 μg/g, 0.0879 μg/g, 245 μg/g and 5.33 μg/g. Compared to other countries, these concentrations were higher. Additionally, tooth type, age and jaw group had no significant effect on heavy material concentrations. Molars have been found to contain higher levels of certain metals than incisors in some studies. In the current study, Brya et al. (12) evaluated toxic material content in impacted third molars and adjacent bone tissue in residents of Wroclaw and the district surrounding it. There was a statistically significant increase in Cd content in the bone and tooth tissue in patients living in Wroclaw ($p = 0.01$). The aim of this work is to review the heavy material content of human teeth dentine. Several analytical techniques are discussed for detecting and quantifying trace elements in teeth, as well as factors influencing element migration in teeth.

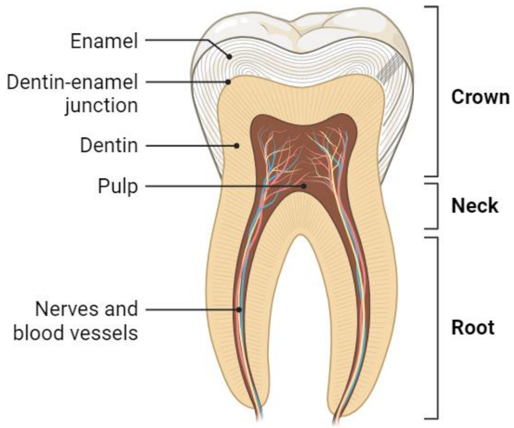

Figure 1. Various component tissues of a tooth.

Components of Teeth

On a histological level, dental hard tissues comprise enamel, dentine and cementum, which are primary components of teeth. Enamel, the most mineralized tissue in the body is composed of 96 wt% in-organic material, followed by (90% amelogenin) organic material such as proteins and 4 wt% water, collagen, lipids (13). Dentin tubule is a hard tissue that lies beneath enamel and contains many channels. The channel allows heat or cold to penetrate the tooth, damaging the enamel. Similarly, damaged enamel causes teeth to be sensitive to heat and cold. Cementum covers the root area of the dentin and anchors periodontal ligament fibres that provide support for mastication and functions during teeth cleaning. Teeth have a middle part cavity filled with soft connective tissue called dental pulp. Blood vessels, nerves, cells and extracellular matrix are part of the connective tissue in the pulp (14). Figure 1 can be shown that Teeth are composed of various tissues.

Human Tooth Mechanical Property Indices

Hardness, elasticity, viscoelasticity and fracture behavior are some of the mechanical properties of teeth. Solid materials' hardness is measured not only by their softness or hardness but also by their resistance to plastic deformation, destruction and elastic deformation, As new methods have evolved, natural teeth' hardness measurements have shifted from macroscopic to microscopic, allowing them to be measured accurately at different spots on an enamel rod (15).

The term elasticity refers to the change in properties that occurs when an external force is applied to a material and then returns to its original state after the force has been removed. In natural teeth, Poisson's ratio, shear modulus and elastic modulus are primarily used to determine elasticity (normal stress ratio to normal strain), shear stress to shear strain, and the ratio of longitudinal extension strain to transverse contraction strain. One of the most extensively studied properties is the elastic modulus (16). Materials with both viscoelasticity and elasticity are called visco-elastic materials, when applied to an external force, it exhibits both viscous and elastic characteristics. Storage modulus and loss modulus are used to determine the viscoelasticity of a material and are known as the composite modulus (17, 18). Fracture mechanical properties are used to study crack growth and strength in materials with crack-type defects. In studies of teeth fracture mechanical properties, fracture toughness of teeth and the crack growth law have been determined, as well as the fatigue crack growth rate (17).

Instrumental Methods of Analysis

Globally, numerical investigations have been conducted to identify possible heavy materials in teeth and carried out using many techniques. First, atomic absorption spectrometry (AAS) have been reported as methods for the detection of trace of elements in various samples (19). Second, X-ray fluorescence analysis (XRF) is used high energy X-ray for specimens which can be analyzed to find out elemental composition without suffering damage or requiring extra preparation (20). Third, inductively coupled plasma mass spectrometry (ICP-MS) is mature and versatile elemental analysis techniques which are used for human teeth analysis and also provides more information about isotopic abundance (21). Fourth, the laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) uses a laser beam to metals from a sample surface when the sample need to determine the elemental composition variation (22). Fifth, laser-induced breakdown spectroscopy (LIBS) is the one of the most common technique that uses laser light for trace material detection in tooth specimens (23). Last one is PIXE (particle induced X-Ray emission) that is a non-destructive, rapid method for analyzing multiple elements simultaneously with parts-per-million sensitivity (24).

Heavy Materials

A heavy material is any metallic chemical element, with a specific gravity greater than 5 times that of water, with a relatively high density. It has been determined that heavy material pollutants in aquatic ecosystems are primarily sourced from anthropogenic sources (25). The toxic effects of heavy materials on humans are well documented. Heavy materials such as chromium (Cr), zinc (Zn), copper (Cu), manganese (Mn), nickel (Ni), and iron (Fe) are essential to the human body, but they are toxic in high concentrations. In trace amounts, Cadmium (Cd) and Lead (Pb) are toxic materials that are not essential to life. Huge number of studies have investigated the concentration of heavy material s in whole teeth in order to find correlations between environmental pollution with heavy materials and samples of teeth (26-28)

Lead (Pb)

In the human environment, element lead (Pb) is the most common heavy material, which can be found everywhere. It has a density of 11.3 g/cm3 and atomic number 82 (29). The lead concentration in deep ocean waters is 0.01-0.02 μg/L, while it is much higher in surface ocean waters is ca. 0.3 μg/L (30). In the present day, lead has a number of important uses which are commonly used as radiation shielding for X-rays and gamma rays due to the high density. A person can become exposed to lead through ingestion, inhalation and dermal contact. The amount of inorganic lead absorbed by humans varies from 20 to 50 percent when inhaled, and from 5 to 15 percent when ingested. In contrast, organic lead is absorbed about 80 percent of the time, and organic lead is readily absorbed when ingested. The teeth and bone of young adults contain more than 95 percent of the total body burden of lead (31). People are exposed to lead from more than one source which makes assessing their risk difficult. The bloodstream distributes lead throughout the body once it has been ingested through the digestive tract (32).

The liver and kidneys are the primary organs affected by lead. The central nervous system, endocrine system, and reproductive system are also affected by lead once it is in the body. A level of exposure to lead is known to be harmful to the organism at any level. Children are particularly vulnerable to lead poisoning which are also exposed to lead in utero through exposure of their mothers (33). There are several factors that affect the amount of lead in teeth, such as age, type of teeth, location, and economic status (34-36). The amount of lead in the dentin and pulp of the dentition increases as the age increases. Lead accumulation is not affected by gender based on previous studies (37).

Studies found that older children have slightly elevated levels of materials, but not significantly. For instance, Asaduzzaman, Alomary and Kern (26, 28, 34) obtained their results from people aged 10, 15 and 20 years old. The study of Bayo focused on the teeth of children under 10 years of age. According to all researchers, cadmium and lead levels in permanent teeth increase with age after age 10. According to Wychowanski and Malkiewicz (38) trace elements were found in third retained molars from patients who lived in rural and urban areas of Mazovia. The authors collected dental material from 30 patients between the ages of 26 and 37. In addition to lead and cadmium, people living in urban areas have significantly higher levels of manganese and chromium in their enamel and dentine than those living in rural areas. A higher cadmium content was observed in tooth tissues in city residents, which increased with advancing age, but was unrelated to gender. In the study of Alomary et al, lead levels in both boys and girls' teeth were significantly different (34). On the other hands, they reported that the concentration of cadmium in girls and boys was similar. According to Alomary et al. (34), dental enamel contained an average of 28.91± 13.70 µg/g dry weight of lead, with a range of 0.74 to 69.15 µg/g dry weight. In previous studies on the Klang valley, Chew et al. (39) found elevated lead levels ranging between 1.7 to 40.5 µg/g, with a mean value of 4.9 µg/g. Table 1 shows research findings on heavy materials from human dentine samples by using some techniques.

Cadmium (Cd)

Cadmium (Cd) is a toxic heavy material that causes bone loss, kidney damage and cancer in humans (40, 41). There are naturally occurring levels of cadmium in the environment, including soil, air, sediments and even unpolluted seawater. A number of countries have strict controls in place on the emissions of Cd to the air from mines, material smelters, battery manufacturers, pigment makers, and plastics manufacturers, though many countries emit cadmium compounds to the air at low levels (42). Cadmium accumulates primarily in the kidneys, bones lungs, placentas, brains and liver in the body. In humans, cadmium has an approximately 10 to 30-year half-life after entering the body. Hence, even low-dose exposure to cadmium can result in its toxicity because it accumulates over time (43). Humans are exposed to the most amount of cadmium through tobacco smoke. All forms of tobacco are significant sources of cadmium. Because lungs absorb cadmium at a much higher rate than gastrointestinal tract, smoking affects the total body burden significantly (1, 44). The hard tissues of teeth are the primary target for Cd, unlike livers and kidneys, but accumulation in their hard tissues influences their morphology and development. According to Al-Jubouri and Bashbosh (45), cadmium levels were detected in blood, teeth, hair and saliva samples of Iraqi workers using AAS. Results indicate that the exposed subjects had increased cadmium concentrations. The effects of cadmium exposure on the teeth are unknown. A study has shown that cadmium inhibits the deposition of iron-containing pigment during enamel's maturation stage (46). This can affect the morphology and development of teeth. Furthermore, the concentration of cadmium in dental enamel is correlated with dental caries susceptibility. Children who are exposed to cadmium are more likely to develop dental caries. Nevertheless, the exact mechanisms and extent of cadmium effects on teeth development and health remain unknown (46). Table 1 shows research findings on heavy materials such as Cd from human dentine samples by using some techniques.

Arsenic (As)
The element arsenic (As) is a rare crystal which naturally occurs in all of earth's environmental media, including sediments, crusts, water, soil and air. The material has been used in a wide range of fields, including electronics, agriculture, medicine, metallurgy, livestock and industry. In recent years, it has risen to the top of the list of toxic agents, posing a significant health threat to humans. The effects of chronic arsenic exposure on human health are far-reaching especially when drinking contaminated groundwater. There is an impact on the development of the fetus, malignancies and skin conditions (47).
Oral health is profoundly affected by toxic materials. Similar to skin melanocytes, those in the oral mucosa's basal cell layer are composed of melanocytes. The sixth most common cancer in the world after oral cavity lesions is oral cancer and it continues to be a leading cause of death globally (48). In addition to these types of oral health problems, arsenic can also damage the vital pulp of the mouth. For instance, arsenic is toxic to the vital pulp, which can result in severe jaw tissue destruction (49). In research by Alhasmi et al. (50), toxic elements such as Pb, As and Cd were measured in the roots of extracted teeth from non-smokers and smokers, using LIBS. The respective elemental concentrations for Pb, As and Cd are 23–29, 0.26–0.31 and 0.64–11 ppm for non-smokers' concentrations, the smokers' concentrations were 35–55, 0.33–0.51and 0.91–1.5 ppm, and the controls' concentrations were 0.17–0.31, 0.01–0.05, and 0.05–0.09 ppm.

Mercury (Hg)
In the environment, Hg exists in a variety of compounds with various properties like toxicity, bioavailability, mobility and volatility. There is no doubt that organomercury compounds have a much higher toxicity than Hg in its inorganic or elemental form. The liver, brain and heart muscle are among the organs and tissues where Hg accumulates. Moreover, it may contribute to diseases such as leukemia by adversely affecting the immune system. For several decades, human health has been concerned over the release of some trace elements in metallic amalgam fillings, especially Hg. After chewing, just for ten minutes, there is a significant amount of Hg vapor released from dental amalgam onto chewing gum (30, 51). Studies by Hoffmann et al. (52) of amalgam toxicity assumed that elemental Hg from the surface of fillings could be inhaled or consumed. Nevertheless, exposure via Hg migration and/or concentration in the calculus, as well as migration into the bloodstream, may significantly confound epidemiological results. Harris et al. (53) investigated the relative significance of mercury migration through dental enamel as an alternative pathway to exposure. An X-ray fluorescence imaging (XRF) study quantified Hg, Zn, Cu and Ca distributions in sections of amalgam-filled teeth that had been in use for over 20 years. Several millimeters away from the amalgams were detected Hg and Zn in the teeth. Compared to Zn, Hg concentrations were higher in dentinal tubules. The chemical form of Hg migrated into the tooth, and was different from the amalgam, was altered by X-ray absorption near-edge spectroscopy (XANES).
Rayad et al. (54) evaluated the content of Mg in impacted wisdom teeth by using atomic absorption spectrometer (AAS) in Legnica-Głogów Copper Area. In addition, the study analysed the correlation between Mg content in the human teeth and vitamin D content in capillary blood, in order to detect variations in Mg content among patients. The research discovered that the concentration of Mg increased with the residence duration and age in this area. Although control group had lower Mg levels than the research group, the difference was not statistically significant. Cardiovascular diseases were significantly associated with higher Mg concentrations in third molars in the control group. The high Mg levels in impacted wisdom teeth may be caused by cardiac diseases.

Other Heavy Materials in Human Teeth
Based on exposure pathways, other heavy materials might be found in human teeth besides Pb, Hg, Cd and As. Dental alloys and certain dental appliances can contain nickel (Ni) which is used in various industrial applications (55). Occasionally, nickel exposure or sensitivity can result in allergic reactions. While, aluminum (Al) is most commonly associated with certain antacids, cookware, and other products, it can also be present in trace amounts in teeth depending on environmental conditions (56). Dental materials and tools contain chromium (Cr) which is used in various industrial processes. In trace amounts, some types of chromium are essential, whereas in higher amounts, they can be harmful (57).

Table 1. Analysis of heavy materials in human teeth using current methods.

Aim	Technique	Sample type	Material detected	Results	References
Lead concentrations in human teeth are studied as a function of age	Atomic absorption spectrometry (AAS)	Teeth	Pb	Approximately 0.1 µg/g of lead is added to the tissues of the teeth each year.	(36)
Study participants in Silesia Province (Poland), which is particularly polluted, were examined for the benefit of using their teeth as an indicator of chronic environmental exposure to Pb	Atomic absorption spectrometry (AAS)	Teeth	Pb	Lead concentrations in primary teeth were significantly higher than in adult teeth. Lead levels in adults' teeth varied based on gender, but not much based on where they lived. Compared with older children, younger children had higher levels of lead in their teeth, suggesting prenatal exposure	(32)
A study was conducted to determine whether material exposure can be assessed using impacted mandibular teeth and the surrounding bones	Atomic absorption spectrometry (AAS)	Teeth	Cd, Pb	Cd and Pb levels in teeth and bone surrounding teeth in Ruda Slaska residents were significantly higher than in Bielsko-Biala residents since this region is relatively polluted	(7)
The distribution of lead in different bone and tooth structures will be evaluated	X-ray fluorescence (XRF)	Teeth	Pb	Roots and pulp of the teeth contained the highest levels of lead	(63)
Identifying the factors that contribute to high dental enamel Pb levels	Graphite furnace atomic absorption spectrometry (GFAAS)	Dental enamel	Pb	Environmental risk factors and dental lead levels were found to be associated	(64)
Cadmium levels were detected in blood, teeth, hair and saliva samples of Iraqi workers	Atomic absorption spectrometry (AAS)	Teeth samples along with saliva, blood and hair	Cd	The exposed subjects had increased cadmium concentrations	(45)
A study in China examined the risk of oral squamous cell carcinoma and Cd levels in dental calculus caused by chewing betel-quid	Inductively coupled plasma mass spectrometry (ICP-MS)	Dental	Cd	Cd levels in dental calculus of men with oral squamous cell carcinoma who chew betel-quid were higher compared to healthy individuals who did not chew the substance.	(65)
Toxic elements such as As, Cd and Pb were measured in the roots of extracted teeth from non-smokers and smokers	laser induced breakdown spectroscopy (LIBS)	Teeth	Pb, As. Cd	The respective elemental concentrations for Pb, As and Cd are 23–29, 0.26–0.31 and 0.64–11 ppm for non-smokers' concentrations , the smokers' concentrations were 35–55, 0.33–0.51and 0.91–1.5 ppm, and the controls' concentrations were 0.17–0.31, 0.01–0.05, and 0.05–0.09 ppm	(50)
Assess the migration of Hg through human teeth as a result of dental amalgam	X-ray fluorescence (XRF)	Teeth	Hg, Zn	More than 20 years after amalgam fillings were removed from human teeth, Hg and Zn were detected. In dentinal tubules, Hg concentrations were higher than Zn concentrations. The chemical form of Hg present in the amalgam had been altered by its migration into the tooth.	(53)

Moreover, manganese (Mn), copper (Cu) and zinc (Zn) are essential trace materials that play a variety of physiological roles in our bodies, but excess amounts can be detrimental (58, 59). A small amount of these materials may be introduced to the body through dental materials and treatments.
Fernández-Escudero et al. (60) analyse the concentration of heavy materials in human teeth and investigate their potential application as age indicators by using ICP-MS. Human teeth were investigated for 25 trace elements which there were five toxic elements ranked in order of concentration: Al > Pb > Sn > Li > As > Cd. In this study, the lowest concentration was found in Cd, while the highest was found in Ca. Furthermore, elements B, Mg, Sr, S, K and Ba with toxic elements, Li, Pb and Sn were detected to increase in coronal dentine with age. A strong correlation with age in premolars and molars is showed by dentine concentrations of K and Pb (60). Heavy material levels by Asaduzzaman et al. examined in human tooth dentine by utilizing ICP-MS instrument for age, gender, ethnicity and tooth type (28). The result of this paper showed that 12 metals were found in human tooth dentine contain Sr, Al, Hg, Cu, Zn, Pb, Cr, Ba, Mn, As and Sb which Sn metal was the most abundant and Cd metal was not contain in the samples. Using laser-induced breakdown spectroscopy (LIBS) technique, Unnikrishnan et al. (61) have been determined the sex and age from teeth specimen for 170 samples in male and female between 15 to 86 years. The main findings for sex and age estimation in tooth specimens showed promising results in forensic applications. Moreover, male teeth samples have lower trace elemental composition than female teeth samples. Using inductively- coupled plasma mass spectrometry (ICP-MS), Zahran NF, et al. reported that the compounds Mn, Na,Cr, Al, Co, K, Cu, Ag, Zn, Bi, Mo and U in the pulp of teeth with caries were lower than those in healthy teeth (62).

Conclusions

Heavy materials are released into the environment around us by both natural and anthropogenic causes, causing environmental pollution such as food and water. Over time, these materials accumulate on human teeth causing decay or gum disease. History of exposure to these substances ranges from early childhood to adulthood. To identify traces of such materials many techniques are utlised which can help researchers in identifying various heavy materials on human teeth. Therefore, it is urgent to prevent further concentrations of these toxic heavy materials through advanced scientific techniques. Unfortunately, their reduction is a difficult task that requires further research. In conclusion, exposure to these heavy materials in our daily lives can have a negative impact on teeth.

Declaration of Interest

None

Author Contributions

The authors contributed to this work together such as conception, design of the review, acquisition of data, drafting and revising the article. Both authors have read and approved the final manuscript.

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