Special Article

J Prev Med Public Health 2014;47:253-257 • http://dx.doi.org/10.3961/jpmph.14.036

pISSN 1975-8375 eISSN 2233-4521

Journal of Preventive Medicine & Public Health

Environmental Source of Arsenic Exposure

Jin-Yong Chung[1], **Seung-Do Yu**[2], **Young-Seoub Hong**[1,3]

[1]Heavy Metal Exposure Environmental Health Center, Dong-A University, Busan; [2]National Institute of Environmental Research, Incheon; [3]Department of Preventive Medicine, Dong-A University College of Medicine, Busan, Korea

Arsenic is a ubiquitous, naturally occurring metalloid that may be a significant risk factor for cancer after exposure to contaminated drinking water, cigarettes, foods, industry, occupational environment, and air. Among the various routes of arsenic exposure, drinking water is the largest source of arsenic poisoning worldwide. Arsenic exposure from ingested foods usually comes from food crops grown in arsenic-contaminated soil and/or irrigated with arsenic-contaminated water. According to a recent World Health Organization report, arsenic from contaminated water can be quickly and easily absorbed and depending on its metabolic form, may adversely affect human health. Recently, the US Food and Drug Administration regulations for metals found in cosmetics to protect consumers against contaminations deemed deleterious to health; some cosmetics were found to contain a variety of chemicals including heavy metals, which are sometimes used as preservatives. Moreover, developing countries tend to have a growing number of industrial factories that unfortunately, harm the environment, especially in cities where industrial and vehicle emissions, as well as household activities, cause serious air pollution. Air is also an important source of arsenic exposure in areas with industrial activity. The presence of arsenic in airborne particulate matter is considered a risk for certain diseases. Taken together, various potential pathways of arsenic exposure seem to affect humans adversely, and future efforts to reduce arsenic exposure caused by environmental factors should be made.

Key words: Arsenic, Arsenic exposure, Drinking water, Cosmetics, Particulate matter

INTRODUCTION

Arsenic, a metalloid and naturally occurring element, is one of the most abundant elements in the earth's crust and is found throughout our environment. Arsenic can attach to very small particles in the air, stay in the air for many days, and travel long distances. Arsenic is primarily used as an insecticide and herbicide or preservative for wood due to its germicidal power and resistance to rotting and decay, respectively. Arsenic is also used in medicine, electronics, and industrial manufacturing [1]. In the environment, arsenic and its compounds are mobile and cannot be destroyed. However, interaction with oxygen or other molecules present in air, water, or soil, as well as with bacteria that live in soil or sediment can cause arsenic to change form, attach to different particles, or separate from these particles [2]. Many common arsenic compounds can dissolve in water, thus arsenic can contaminate lakes, rivers, or underground water by dissolving in rain, snow, or through discarded industrial wastes. Therefore, arsenic contamination in ground water is a serious public health threat worldwide. In addition, the effect of chronic arsenic exposure from ingested arsenic-contaminated food and water or inhaled contaminated air has been investigated in various countries and found to be associated with detrimental health effects such as hyperpigmentation, keratosis, various types of cancer and vascular diseases [3,4]. According to a recent publication by the US Agency for Toxic

Received: August 19, 2014 Accepted: September 6, 2014
Corresponding author: Young-Seoub Hong, MD, PhD
26 Daesingongwon-ro, Seo-gu, Busan 602-715, Korea
Tel: +82-51-240-2888, Fax: +82-51-253-5729
E-mail: yshong@dau.ac.kr

Substances and Disease Registry, arsenic exposure through inhalation and the dermal layer is considered a minor route for exposure in the general population, but a major route for occupational workers. In the general population, oral arsenic exposure is the predominant exposure route. Hence, most diets are the largest source of arsenic exposure. In addition, ingestion of small concentrations of arsenic in dust or soil through regular hand-to-mouth activities may be an important route of exposure among young children [5].

Once arsenic compounds are absorbed, they are generally processed via the liver's metabolic pathway, and then converted into many different types of inorganic and organic species including arsenite (As^{3+}), arsenate (As^{5+}), dimethylarsinate (DMA), and monomethylarsonate (MMA). Inorganic arsenic and organic arsenic are absorbed quickly into the blood and circulated to the human gastrointestinal tract. Organic arsenic species are generally considered innocuous since they are poorly absorbed into cells [6]. In contrast, inorganic arsenic species are highly reactive and affect a series of intracellular reactions [7]. Eventually, arsenic metabolites in the body are excreted in the urine, the major excretion pathway for the elimination of arsenic species from the body. Each form of arsenic has different physiological and bioactive properties, hence it is necessary to identify and quantify each chemical form of arsenic to evaluate their individual effects on human health. Although the total arsenic concentration (total concentration of DMA, MMA, and inorganic arsenic) has been used by previous studies, it is not considered a sufficient measurement for health risk assessment [8,9]. One reason is that the toxicity of arsenic is strongly dependent on the type of chemical species present in the body. It is generally recognized that inorganic arsenic is more toxic than organic arsenic (DMA and MMA), and among inorganic arsenic, As^{3+} is more toxic than As^{5+} [10-12]. In most animal studies, DMA has been the main metabolite, while in humans, urinary excretion analysis under normal conditions have revealed approximately 20% inorganic arsenic, 20% MMA, and 60% DMA [13,14]. Therefore, arsenic levels measured in the urine can be used as a biomarker of arsenic exposure in humans. Since arsenic is rapidly metabolized and excreted through the urine, this measurement can provide evidence of recent arsenic exposures [15].

During last decade, arsenic pollution has been considered an important environmental issue in many countries worldwide. However, the environmental route of exposure causing arsenic contamination in the general population has not been fully determined. Recently, the most significant concern related to human health risks from arsenic toxicity is thought to be transported through drinking water, worldwide food distribution, smoking, and global cosmetics. Herein, we review the possible routes for environmental arsenic exposure in humans and potential health risks due to chronic arsenic exposure.

POTENTIAL PATHWAYS OF ARSENIC EXPOSURE IN HUMANS

Drinking Water

Ground water is a major source of drinking water, and elevated concentration of arsenic in ground water has been associated with various negative health effects in humans [16,17]. Arsenic in drinking water is considered one of the most significant environmental causes of cancer in the world. Consequently, since 1963, the World Health Organization has recommended limits to the maximum concentrations of arsenic in drinking water. In 1963, their recommendation was of 50 µg/L, but after new evidence relating low arsenic concentrations with cancer risk, the World Health Organization further reduced their recommendation to 10 µg/L in 1992 [18-20]. Contamination of ground water is one of the major pathways of human exposure to inorganic arsenic and the risk of arsenic contamination is generally much higher in ground water than that in surface water [21]. Elevated concentrations of arsenic in ground water have been reported in Bangladesh [22-24], Vietnam [25], China [26], Taiwan [27], Argentina [28,29], and Canada [30]. Elevated concentrations of arsenic have primarily resulted from natural sources, such as erosion and leaching from geological formations or anthropogenic sources. In addition, arsenic use for industrial purposes, mining activities, metal processing, and pesticides and fertilizers are other major source of contamination.

Industrial Manufacturing and Wood Preservatives

Most arsenic used in industrial processes is used to produce antifungal wood preservatives that can lead soil contamination. Incineration of preserved wood products, pressure treated with chromate copper arsenate was found to be a source of environmental arsenic contamination [31]. According to the publication by the US Agency for Toxic Substance and Disease Registry, since 2003, the use of arsenic-containing wood preservatives have been phased out for certain residential uses such as play structures, picnic tables, decks, fencing, and boardwalks, but are still used in industrial applications. Arsenic is also used in the pharmaceutical and glass industries, in the manufacturing of alloy, sheep dips, leather preservatives, arsenic-containing pigments, antifouling paints, and poison baits. Arsenic compounds are also employed in the microelectronics and optical industries [32]. In addition, arsenic has been widely used in insecticides and pesticides due to its germicidal power, but the use of inorganic arsenic compounds in pesticides is no longer permitted in North America. The inorganic arsenic compounds, primarily, sodium arsenite, have been widely used as a weed killer, and non-selective soil sterilant [33].

Smoking

Some reports have indicated that smoking is associated with a decreased ability to methylate ingested arsenic. Previous studies have also shown that cigarette smokers have a significantly higher total urinary arsenic concentration and MMA concentration than non-smokers do [34]. One possibility is that some chemicals in cigarettes compete for different enzymes or co-factors involved in the arsenic methylation process. In addition, cigarettes may also contain some arsenic; one study estimated that approximately 0.25 μg of arsenic is ingested after smoking one cigarette [35]. Although cigarette smoking is already a main risk factor for lung cancer, Ferreccio et al. [36] found that cigarette smoking and ingesting arsenic in drinking water had a synergistic effect. Some of arsenic metabolites found in the urine may result from arsenic exposure due to cigarettes smoking. Therefore, arsenic exposure from cigarettes smoking may also be a serious health concern especially in communities with high concentrations of arsenic in the drinking water [37]. Cigarette use has been found to be correlated with an elevated risk of bladder cancer. In one US study, smokers exposed to high concentrations of arsenic in drinking water (200 μg/L), had a higher risk of bladder cancer than smokers exposed to low concentrations of arsenic did [38,39].

Diet

Consumption of food grown in arsenic-contaminated areas is another source of chronic arsenic exposure, since agricultural products have been found to be cultivated using arsenic-contaminated ground water. Chakraborti et al. [40] confirmed that contaminated ground water used to cultivate vegetables and rice for human consumption may be an important pathway of arsenic ingestion. Another study investigated the concentration of arsenic in food imported into the United Kingdom and found that vegetables imported from Bangladesh had a 2 to 100-fold higher concentration of arsenic than that of vegetables cultivated in the United Kingdom and North America [41]. However, the type of arsenic species found in these foods was not reported. This information is necessary to assess the risk among humans who ingest these foods. Nevertheless, this study further supports the theory that food may be an important route of arsenic exposure in some regions and that these exposures may have long-term negative health effects in humans. Considering the widespread distribution of food, arsenic-contaminated food and the possible associated risks of disease should be considered an important global issue. It is also well known that some crustaceans contain arsenobetaine and some seaweed contains arsenosugar, but seafood usually contains organic arsenic compounds that are less toxic than inorganic counterparts are [42].

Cosmetic

Cosmetics are of low priority in consumer safety assessments since they are wrongly assumed to have no effect our health. Cosmetics are also considered an unlikely source of arsenic exposure and as a simple impurity, but are a leading cause of direct exposure among a many individuals. Assessing the amount of dermal absorption from a single component in a cosmetic product is complex and depends on many factors such as the concentration of arsenic in the product, the amount of product applied, the length of time left on the skin and the presence of emollients and penetration enhancers in the cosmetic product [43]. Currently, no international standard for impurities, such as heavy metals, in cosmetics exist. However, some countries have conducted tests to determine the levels of heavy metal contents in cosmetic products and provided some guidelines for limiting use [44,45].

Air

In air, arsenic exists predominantly attached to particulate matter, and is usually present as a mixture of arsenite and arsenate, with a negligible amount of organic arsenic species except in areas using arsenic pesticides or with biotic activity. One previous study suggested that methylated arsenic is a minor component in the air of suburban, urban and industrial areas, and that the major inorganic portion of air is composed of the trivalent and pentavalent compounds [46]. Human exposure to arsenic through the air generally occurs at very low concentrations ranging from 0.4 to 30 ng/m^3. The US Environmental Protection Agency has estimated that approximately 40 to 90 ng of arsenic per day are typically inhaled by humans. In unpolluted areas, approximately 50 ng or less arsenic is inhaled per day [47].

CONCLUSION

The ingestion of arsenic by humans can cause a variety of disorders, including skin lesions problems with the respiratory and/or nervous systems, and different types of cancers. Certain pathways have been found to result in arsenic exposure in humans, such as from drinking water, foods, cigarettes, certain residential areas, occupational environment, and cosmetics. Guidelines to keep the concentration of arsenic in drinking water to 50 μg/L or lower has not been found to be protective, and the World Health Organization has decreased their recommendation to 10 μg/L. Because ground water can contain high concentrations of arsenic, drinking water sources should be tested for arsenic and carefully monitored. The methylation of arsenic can also be influenced by a variety of environmental factors mentioned above. We hope that this careful review of possible source of arsenic exposure will contribute to reducing arsenic-related health hazards in humans.

CONFLICT OF INTEREST

The authors have no conflicts of interest with the material presented in this paper.

REFERENCES

1. Nriagu JO, Azcue JM. Arsenic in the environment. Part I. Cycling and characterization. New York: Wiley; 1990, p. 1-15.
2. Fergusson JE. The heavy elements: chemistry, environmental impact, and health effects. New York: Pergamon Press; 1990, p. 362-365.
3. Gibb H, Haver C, Gaylor D, Ramasamy S, Lee JS, Lobdell D, et al. Utility of recent studies to assess the National Research Council 2001 estimates of cancer risk from ingested arsenic. Environ Health Perspect 2011;119(3):284-290.
4. Argos M, Kalra T, Rathouz PJ, Chen Y, Pierce B, Parvez F, et al. Arsenic exposure from drinking water, and all-cause and chronic-disease mortalities in Bangladesh (HEALS): a prospective cohort study. Lancet 2010;376(9737):252-258.
5. Agency for Toxic Substances and Disease Registry. Public health statement for arsenic [cited 2014 Sep 16]. Available from: http://www.atsdr.cdc.gov/phs/phs.asp?id=18&tid=3.
6. Akter KF, Owens G, Davey DE, Naidu R. Arsenic speciation and toxicity in biological systems. Rev Environ Contam Toxicol 2005;184:97-149.
7. Drobná Z, Walton FS, Paul DS, Xing W, Thomas DJ, Stýblo M. Metabolism of arsenic in human liver: the role of membrane transporters. Arch Toxicol 2010;84(1):3-16.
8. Hakala E, Pyy L. Assessment of exposure to inorganic arsenic by determining the arsenic species excreted in urine. Toxicol Lett 1995;77(1-3):249-258.
9. Ma M, Le XC. Effect of arsenosugar ingestion on urinary arsenic speciation. Clin Chem 1998;44(3):539-550.
10. Hindmarsh JT, McCurdy RF. Clinical and environmental aspects of arsenic toxicity. Crit Rev Clin Lab Sci 1986;23(4):315-347.
11. Valentine JL, Kang HK, Spivey G. Arsenic levels in human blood, urine, and hair in response to exposure via drinking water. Environ Res 1979;20(1):24-32.
12. Buchet JP, Lauwerys R, Roels H. Urinary excretion of inorganic arsenic and its metabolites after repeated ingestion of sodium metaarsenite by volunteers. Int Arch Occup Environ Health 1981;48(2):111-118.
13. Vahter M, Marafante E, Dencker L. Tissue distribution and retention of 74As-dimethylarsinic acid in mice and rats. Arch Environ Contam Toxicol 1984;13(3):259-264.
14. Buchet JP, Lauwerys R, Roels H. Comparison of the urinary excretion of arsenic metabolites after a single oral dose of sodium arsenite, monomethylarsonate, or dimethylarsinate in man. Int Arch Occup Environ Health 1981;48(1):71-79.
15. Buchet JP, Lison D, Ruggeri M, Foa V, Elia G. Assessment of exposure to inorganic arsenic, a human carcinogen, due to the consumption of seafood. Arch Toxicol 1996;70(11):773-778.
16. Bhattacharya P, Jacks G, Ahmed KM, Routh J, Khan AA. Arsenic in groundwater of the Bengal delta plain aquifers in Bangladesh. Bull Environ Contam Toxicol 2002;69(4):538-545.
17. Bhattacharya P, Jacks G, Frisbie SH, Smith E, Naudu R, Sarkar B. Arsenic in the environment: a global perspective. In: Sarker B, editor. Handbook of heavy metals in the environment. New York: Marcel Dekker; 2001, p. 145-215.
18. World Health Organization. Guidelines for drinking-water quality: recommendations. Geneva: World Health Organization; 1993, p. 1-11.
19. World Health Organization. Environmental health criteria 224: arsenic and arsenic compounds. 2nd ed. Geneva: World Health Organization; 2001, p. 1-7.
20. Environmental Protection Agency. National interim primary

drinking water regulations; 1976 [cited 2014 Sep 28]. Available from: http://yosemite.epa.gov/water/owrcCatalog.nsf/9da204a4b4406ef885256ae0007a79c7/490344d9eaf40d4e85256b0600724162!OpenDocument.
21. Argos M, Ahsan H, Graziano JH. Arsenic and human health: epidemiologic progress and public health implications. Rev Environ Health 2012;27(4):191-195.
22. Chowdhury UK, Biswas BK, Chowdhury TR, Samanta G, Mandal BK, Basu GC, et al. Groundwater arsenic contamination in Bangladesh and West Bengal, India. Environ Health Perspect 2000;108(5):393-397.
23. Karim MM. Arsenic in groundwater and health problem in Bangladesh. Water Res 2000;34(1):304-310.
24. Mukherjee AB, Bhattacharya P. Arsenic in groundwater in the Bengal Delta Plain: slow poisoning in Bangladesh. Environ Rev 2001;9(3):189-220.
25. Berg M, Tran HC, Nguyen TC, Pham HV, Schertenleib R, Giger W. Arsenic contamination of groundwater and drinking water in Vietnam: a human health threat. Environ Sci Technol 2001;35(13):2621-2626.
26. Lianfang W, Jianzhong H. Chronic arsenicism from drinking water in some areas of Xinjiang, China. In: Nriagu J, editor. Arsenic in the environment. Part II. Human health and ecosystem effects. Chichester: Wiley; 1994, p.159-172.
27. Chen SL, Dzeng SR, Yang MH, Chiu KH, Shieh GM, Wai CM. Arsenic species in groundwaters of the blackfoot disease area, taiwan. Environ Sci Technol 1994;28(5):877-881.
28. Smedley PL, Kinniburgh DG, Nicolli HB, Barros AJ, Tullio JO, Pearce JM, et al. Arsenic associations in sediments from the loess aquifer of La Pampa, Argentina. Appl Geochem 2005;20(5):989-1016.
29. Bundschuh J, Farias B, Martin R, Storniolo A, Bhattacharya P, Cortes J, et al. Groundwater arsenic in the Chaco-Pampean Plain, Argentina: case study from Robles county, Santiago del Estero ProvinceOriginal. Appl Geochem 2004;19(2):231-243.
30. Grantham DA, Jones JF. Arsenic contamination of water wells in Nova Scotia. J Am Water Works Assoc 1977;69(12):653-657.
31. Lu FJ. Blackfoot disease: arsenic or humic acid? Lancet 1990;336(8707):115-116.
32. International Program on Chemical Safety. Arsine: human health aspects. Geneva: World Health Organization; 2002, p. 1-36.
33. US Department of Agriculture. The pesticides review. Washington, DC: US Department of Agriculture; 1970, p. 46.
34. Tseng CH. Blackfoot disease and arsenic: a never-ending story. J Environ Sci Health C Environ Carcinog Ecotoxicol Rev 2005;23(1):55-74.
35. Agency for Toxic Substances and Disease Registry. Toxicological profile for arsenic. Atlanta: Agency for Toxic Substances and Disease Registry; 1993, p. 57-73.
36. Ferreccio C, Gonzalez C, Milosavjlevic V, Marshall G, Sancha AM, Smith AH. Lung cancer and arsenic concentrations in drinking water in Chile. Epidemiology 2000;11(6):673-679.
37. Kazi TG, Arain MB, Baig JA, Jamali MK, Afridi HI, Jalbani N, et al. The correlation of arsenic levels in drinking water with the biological samples of skin disorders. Sci Total Environ 2009;407(3):1019-1026.
38. Morales KH, Ryan L, Kuo TL, Wu MM, Chen CJ. Risk of internal cancers from arsenic in drinking water. Environ Health Perspect 2000;108(7):655-661.
39. Steinmaus C, Yuan Y, Bates MN, Smith AH. Case-control study of bladder cancer and drinking water arsenic in the western United States. Am J Epidemiol 2003;158(12):1193-1201.
40. Chakraborti D, Sengupta MK, Rahman MM, Ahamed S, Chowdhury UK, Hossain MA, et al. Groundwater arsenic contamination and its health effects in the Ganga-Meghna-Brahmaputra plain. J Environ Monit 2004;6(6):74N-83N.
41. Al Rmalli SW, Haris PI, Harrington CF, Ayub M. A survey of arsenic in foodstuffs on sale in the United Kingdom and imported from Bangladesh. Sci Total Environ 2005;337(1-3):23-30.
42. Le XC, Cullen WR, Reimer KJ. Human urinary arsenic excretion after one-time ingestion of seaweed, crab, and shrimp. Clin Chem 1994;40(4):617-624.
43. Hostynek JJ. Toxic potential from metals absorbed through the skin [cited 2014 Sep 25]. Available from: http://www.cosmeticsandtoiletries.com/research/biology/42552997.html.
44. Canada Environmental Defence. Heavy metal hazard: the health risks of hidden heavy metals in face makeup; 2011 [cited 2014 Sep 16]. Available from: http://environmentaldefence.ca/reports/heavy-metal-hazard-health-risks-hidden-heavy-metals-in-face-makeup.
45. India Centre for Science and Environment. Heavy metals in cosmetics. New Delhi: India Centre for Science and Environment; 2014, p. 1-28.
46. Environmental Pro.tection Agency. Health assessment document for inorganic arsenic. Research Triangle Park: Environmental Protection Agency; 1983, p. 351.
47. Environmental Protection Agency. Inorganic arsenic: toxicity and exposure assessment for children's health [cited 2014 Sep 16]. Available from: http://www.epa.gov/teach/chem_summ/Arsenic_summary.pdf.