Communicative & Integrative Biology 6:6, e26369; November/December 2013; © 2013 Landes Bioscience

Aluminum and the human diet revisited

Christopher A Shaw[1]* and Thomas E Marler[2]

[1]University of British Columbia, Departments of Ophthalmology and Medical Science, Experimental Medicine, and Graduate Program in Neuroscience; Vancouver, BC Canada; [2]Western Pacific Tropical Research Center; University of Guam; UOG Station; Mangilao, Guam USA

Concerns about aluminum (Al) exposure in the human diet have persisted for one century. We suggest that continued research would benefit from better reporting of environmental factors that are known to influence Al accumulation in plant organs that are consumed, focusing on subsets of the general public that exhibit the highest risk for neuropathological responses, increased evaluation of commercial processing procedures that may concentrate Al or other toxic substances, and designing studies with low dose, chronic exposure rather than solely on further study of acute, brief exposure.

Keywords: adjuvant, autoimmunity, neurodegeneration, neurotoxins, traditional medicine

Submitted: 09/01/2013; Accepted: 09/03/2013

Citation: Shaw CA, Marler TE. Aluminum and the human diet revisited. Communicative & Integrative Biology 2013; 6:e26369; http://dx.doi.org/10.4161/cib.26369

*Correspondence to: Christopher A Shaw; Email: cashawlab@gmail.com

Marler TE, Yang J. Risk of aluminum exposure from noni (Morinda citrifolia L.) leaf products. Econ Bot 2013; http://dx.doi.org/10.1007/s12231-013-9236-5, In press.

Introduction

Traditional medicines derived from botanical products have been used in regions such as Africa, Asia, and India for many years.[1,2] The use of herbal materials in medicines, food supplements, and teas has increased substantially in Western countries in recent years, leading to concerns about safety assessment of these products.[3-6] Noni (*Morinda citrifolia*) is a popular species for formulating home, regional, and international products for human consumption, and this led us to evaluate the potential for excessive Aluminum (Al) exposure via ingestion of noni leaf products.[7] We reported that Al accumulation in leaves could pose a health risk in some situations, such as harvest of old leaves from trees growing in volcanic soils.

Aluminum is the most abundant metal and one of the most common elements in the Earth's crust. As a metal, it is light, strong, durable, resistant to corrosion, and a good conductor of electricity. Over the past 200 years, refined Al has found its way into a variety of industrial and materials applications.[8] From the early 1800s Al became increasingly bioavailable due to its extraction from bauxite and other compounds. It is now found in numerous products such as industrial applications, in various processed foods as an anti-caking agent, in water treatment as a flocculant, and in a variety of medicinal products, antiperspirants, and cosmetics. In regard to medicinals, it is commonly used as an adjuvant in vaccines.

Aluminum not Inert

Geologically, Al is normally bound into molecular complexes, usually those involving silicates. For this reason, Al appears to have no known role in any normal biochemistry on Earth. Some researchers have gone further to suggest that Al has been "selected out" of evolution due to its lack of bioavailability.[9] Aluminum is routinely toxic where it does occur in living systems.[10-13] However, growth of pathological cells such as some cancers may be enhanced by Al.[14]

As an element, Al is extremely avid and binds to then interferes with many molecules essential for life, notably carbon, oxygen, sulfur, and phosphorus among others. It also binds to fluoride, forming highly toxic aluminoflouride compounds.[15] Concerns over the potential for Al toxicity in human food and drink products have persisted for a century.[16] Aluminum toxicity was later discounted as an etiological factor in Alzheimer disease as the amounts available

from food, water, or aluminum cookware were usually found to be low. A rather large body of evidence by various investigators now shows that chronic exposure to Al can be highly neurotoxic and may indeed have a link to Alzheimer disease.[17-19]

Neurological Disorders

Cognitive decline and central nervous system (CNS) pathologies that resemble those of Alzheimer are induced by Al in older rats.[20] Soil and water sources of Al were implicated in the ALS-parkinsonism dementia complex on Guam.[21] Additionally, the acute effects of higher doses of Al-induced dialysis associated encephalopathy in humans are well documented.[22]

The route of administration of Al plays a key role in the type of neurotoxicity exhibited. While most dietary Al is removed by the kidneys, those lacking mature or patent kidney function such as pediatric and geriatric subjects may be more likely to accumulate Al in different organs, including the CNS. Injected Al from Al adjuvants in vaccines have a very different fate and appear to be picked up from the draining lymph nodes by circulating macrophages and transported into the CNS.[23] Motor neuron loss following Al hydroxide injections in mice and sheep[24-26] and macrophagic myofasciitis in humans involving cognitive dysfunction in humans has been reported.[27] Al adjuvants have also been linked to a series of autoimmune disorders in humans.[28]

Developmental neurological disorders such as autism spectrum disorder (ASD) also have a potential Al link through the accumulative weight of pediatric vaccines, many of which contain Al as adjuvants.[29] Indeed, there is a highly significant correlation between ASD rates and cumulative Al adjuvant amount,[30] a correlation that satisfies eight of nine Hill criteria for causality. Similar outcomes are found in newborn mice injected with Al adjuvants.[31] A recent review also links Al to ASD.[32]

Areas of Concern

To view Al in biological systems as either inert or without toxic consequence is to ignore a rapidly growing body of evidence to the contrary. Inter-disciplinary teams may offer the most efficient means of advancing our understanding of risks of Al exposure in the human diet and from other sources. The following are issues to guide ongoing research.

•Aluminum availability to plants is governed by soil pH, and in accumulator plant species by age of organ. Our study revealed that young noni leaves from trees growing in alkaline soils posed minimal calculated risk, but old leaves from trees growing in acidic soils posed the greatest risk.[7] During recent years, substantial advances have been made in understanding the mechanisms of Al toxicity in plants and approaches to assess the potentially toxic Al species in environmental samples.[33] Yet soil traits, harvested organ age, and other arguably mandatory experimental details are omitted from research articles on traditional knowledge and folk medicines. These omissions do not acknowledge the current status of knowledge and disallow adequate comparisons among studies.

•Consumption of unprocessed herbal products or home concoctions carries relatively minimal risk of excessive Al exposure. However, superfruits, nutritional therapeutics, neutraceuticals, and functional foods are among the arsenal of innovative marketing strategies to reach consumers who demand what they believe to be healthy food options.[34-36] Some commercial procedures concentrate herbal products, then boast about the supposed added benefits of the concentrated product. These processing and concentrating steps may take a raw herbal product that carries minimal risk and turn it into an internationally marketed product that carries greater risk.

•Risks of Al toxicity are elevated for some easily defined subsets of the general public. For example, infants and small children carry greater risk because intake limits are based on body weight. Individuals with kidney immaturity or abnormalities because the normal pathway for excreting aluminum from the body is via urine and feces.[37] Continued research on pediatric, geriatric, and other high risk groups rather than the general population may increase the efficiency of research.

•Numerous investigations have revealed that the chronic component of exposure to Al is what leads to neurotoxicity.[8,17] The body burden of Al is spread among various tissues, but incremental doses of small amounts of Al over a lifetime favor brain tissues as the site of bioaccumulation. This form of exposure reproduces neuropathological traits of Alzheimer disease. Long-term studies on chronic exposure to Al should be the thrust of dietary research.

•Al compounds are numerous, and the biological responses may be highly specific to the form of Al to which the body is exposed. Studies should be specific to the form of aluminum administered.

A high percentage of the world's population uses alternative self-medication and herbal treatments for prophylactic purposes without being aware of the possible toxic components and toxin synergies that may impact their health. When these herbal treatments inadvertently contain Al or other known toxicants, environmental conditions, post-harvest treatment in processing, and age, general health, and genetic traits of the consumer are factors that may increase risk of developing neurological disorders. These examples illuminate why the public should be better informed on potential health risks associated with using herbal products in self-medication.[38]

Disclosure of Potential Conflicts of Interest

No potential conflicts of interest were disclosed.

References

1. Kamboj VP. Herbal medicine. Curr Sci 2000; 78:35-9
2. World Health Organization. Traditional medicine. Geneva, WHO. 2003.
3. Pal SK, Shukla Y. Herbal medicine: current status and the future. Asian Pac J Cancer Prev 2003; 4:281-8; PMID:14728584
4. Rietjens IM, Slob W, Galli C, Silano V. Risk assessment of botanicals and botanical preparations intended for use in food and food supplements: emerging issues. Toxicol Lett 2008; 180:131-6; PMID:18602975; http://dx.doi.org/10.1016/j.toxlet.2008.05.024
5. Sanzini E, Badea M, Santos AD, Restani P, Sievers H. Quality control of plant food supplements. Food Funct 2011; 2:740-6; PMID:21847499; http://dx.doi.org/10.1039/c1fo10112a

6. van den Berg SJ, Serra-Majem L, Coppens P, Rietjens IM. Safety assessment of plant food supplements (PFS). Food Funct 2011; 2:760-8; PMID:21804969; http://dx.doi.org/10.1039/c1fo10067j
7. Marler TE, Yang J. Risk of aluminum exposure from noni (Morinda citrifolia L.) leaf products. Econ Bot 2013; In press; PMID:23538880; http://dx.doi.org/10.1007/s12231-013-9236-5.
8. Shaw CA, Tomljenovic L. Aluminum in the central nervous system (CNS): toxicity in humans and animals, vaccine adjuvants, and autoimmunity. Immunol Res 2013; 56:304-16; PMID:23609067; http://dx.doi.org/10.1007/s12026-013-8403-1
9. Exley C. Darwin, natural selection and the biological essentiality of aluminium and silicon. Trends Biochem Sci 2009; 34:589-93; PMID:19773172; http://dx.doi.org/10.1016/j.tibs.2009.07.006
10. Exley C. The coordination chemistry of aluminium in neurodegenerative disease. Coord Chem Rev 2012; 256:2142-6; http://dx.doi.org/10.1016/j.ccr.2012.02.020
11. Exley C, Birchall JD. The cellular toxicity of aluminium. J Theor Biol 1992; 159:83-98; PMID:1291812; http://dx.doi.org/10.1016/S0022-5193(05)80769-6
12. Exley C, Burgess E, Day JP, Jeffery EH, Melethil S, Yokel RA. Aluminum toxicokinetics. J Toxicol Environ Health 1996; 48:569-84; PMID:8772799; http://dx.doi.org/10.1080/009841096161078
13. Krewski D, Yokel RA, Nieboer E, Borchelt D, Cohen J, Harry J, Kacew S, Lindsay J, Mahfouz AM, Rondeau V. Human health risk assessment for aluminium, aluminium oxide, and aluminium hydroxide. J Toxicol Environ Health B Crit Rev 2007; 10(Suppl 1):1-269; PMID:18085482; http://dx.doi.org/10.1080/10937400701597766
14. Darbre PD. Underarm cosmetics are a cause of breast cancer. Eur J Cancer Prev 2001; 10:389-93; PMID:11711753; http://dx.doi.org/10.1097/00008469-200110000-00002
15. Strunecká A, Patocka J. Aluminofluoride complexes in the etiology of Alzheimer's disease. Struct Bond 2003; 104:139-80; http://dx.doi.org/10.1007/3-540-45425-X_5
16. Gies WJ. Some objections to the use of alum baking-powder. JAMA 1911; 57:816-21; http://dx.doi.org/10.1001/jama.1911.04260090038015
17. Tomljenovic L. Aluminum and Alzheimer's disease: after a century of controversy, is there a plausible link? J Alzheimers Dis 2011; 23:567-98; PMID:21157018
18. Yokel RA, McNamara PJ. Aluminium toxicokinetics: an updated minireview. Pharmacol Toxicol 2001; 88:159-67; PMID:11322172; http://dx.doi.org/10.1034/j.1600-0773.2001.d01-98.x
19. Exley C, Esiri MM. Severe cerebral congophilic angiopathy coincident with increased brain aluminium in a resident of Camelford, Cornwall, UK. J Neurol Neurosurg Psychiatry 2006; 77:877-9; PMID:16627535; http://dx.doi.org/10.1136/jnnp.2005.086553
20. Walton JR, Wang MX. APP expression, distribution and accumulation are altered by aluminum in a rodent model for Alzheimer's disease. J Inorg Biochem 2009; 103:1548-54; PMID:19818510; http://dx.doi.org/10.1016/j.jinorgbio.2009.07.027
21. Garruto RM, Fukatsu R, Yanagihara R, Gajdusek DC, Hook G, Fiori CE. Imaging of calcium and aluminum in neurofibrillary tangle-bearing neurons in parkinsonism-dementia of Guam. Proc Natl Acad Sci U S A 1984; 81:1875-9; PMID:6584922; http://dx.doi.org/10.1073/pnas.81.6.1875
22. Flendrig JA, Kruis H, Das HA. Aluminium intoxication: The cause of dialysis dementia? Proc Eur Dial Transplant Assoc 1976; 13:355-68
23. Khan Z, Combadière C, Authier FJ, Itier V, Lux F, Exley C, Mahrouf-Yorgov M, Decrouy X, Moretto P, Tillement O, et al. Slow CCL2-dependent translocation of biopersistent particles from muscle to brain. BMC Med 2013; 11:99; PMID:23557144; http://dx.doi.org/10.1186/1741-7015-11-99
24. Petrik MS, Wong MC, Tabata RC, Garry RF, Shaw CA. Aluminum adjuvant linked to Gulf War illness induces motor neuron death in mice. Neuromolecular Med 2007; 9:83-100; PMID:17114826; http://dx.doi.org/10.1385/NMM:9:1:83
25. Shaw CA, Petrik MS. Aluminum hydroxide injections lead to motor deficits and motor neuron degeneration. J Inorg Biochem 2009; 103:1555-62; PMID:19740540; http://dx.doi.org/10.1016/j.jinorgbio.2009.05.019
26. Lujan L, Perez M, Salazar E, et al. Autoimmune/autoinflammatory syndrome induced by adjuvants ASIA syndrome in commercial sheep. Immunol Res 2013; [epub ahead of print] 10.1007/s12026-013-8404-0.
27. Gherardi RK, Coquet M, Cherin P, Belec L, Moretto P, Dreyfus PA, Pellissier JF, Chariot P, Authier FJ. Macrophagic myofasciitis lesions assess long-term persistence of vaccine-derived aluminium hydroxide in muscle. Brain 2001; 124:1821-31; PMID:11522584; http://dx.doi.org/10.1093/brain/124.9.1821
28. Shoenfeld Y, Agmon-Levin N. 'ASIA' - autoimmune/inflammatory syndrome induced by adjuvants. J Autoimmun 2011; 36:4-8; PMID:20708902; http://dx.doi.org/10.1016/j.jaut.2010.07.003
29. Tomljenovic L, Shaw CA. Aluminum vaccine adjuvants: are they safe? Curr Med Chem 2011; 18:2630-7; PMID:21568886; http://dx.doi.org/10.2174/092986711795933740
30. Tomljenovic L, Shaw CA. Do aluminum vaccine adjuvants contribute to the rising prevalence of autism? J Inorg Biochem 2011; 105:1489-99; PMID:22099159; http://dx.doi.org/10.1016/j.jinorgbio.2011.08.008
31. Shaw CA, Li Y, Tomljenovic L. Administration of aluminium to neonatal mice in vaccine-relevant amounts is associated with adverse long term neurological outcomes. J Inorg Biochem 2013; In press; PMID:23932735; http://dx.doi.org/10.1016/j.jinorgbio.2013.07.022.
32. Seneff S, Davidson RM, Liu J. Empirical data confirm autism symptoms related to aluminum and acetaminophen exposure. Entropy 2012; 14:2227-53; http://dx.doi.org/10.3390/e14112227
33. Poschenrieder C, Gunsé B, Corrales I, Barceló J. A glance into aluminum toxicity and resistance in plants. Sci Total Environ 2008; 400:356-68; PMID:18657304; http://dx.doi.org/10.1016/j.scitotenv.2008.06.003
34. Brown A. Understanding food: Principles and preparation. 2010.
35. Crawford K, Mellentin J. Successful Superfruit strategy: How to build a superfruit business. Cambridge, England, Woodhead Publishing. 2008.
36. Schardt D. Super fruit: Squeezing cold cash out of three 'hot' juices. Nutrition Action Healthletter Nov 2006: 9–11.
37. Agency for Toxic Substances and Disease Registry. Public Health Statement Aluminum CAS#:7429-90-5. U.S. Department of Health and Human Services, Atlanta, Georgia. 2008.
38. Ernst E. Herbal medicines: where is the evidence? BMJ 2000; 321:395-6; PMID:10938031; http://dx.doi.org/10.1136/bmj.321.7258.395