Human Health Effects of Dietary Aluminum

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Résumé :

(traduction)

On retrouve l'aluminium en abondance dans l'environnement : on en trouve notamment dans la plupart des aliments. À ce jour, il n'y a pas d'ensemble de données suffisamment convaincant pour nous renseigner sur les risques pour la santé lié à l'ingestion d'aluminium à travers la nourriture, l'eau et les produits pharmaceutiques. Cet article cherche à examiner l'ensemble de la littérature existante sur le sujet en quête de données sur les effets de l'absorption d'aluminium dans l'alimentation sur la santé.

Notre revue de littérature démontre que les données existantes sont contradictoires et, qu'en tant que tel, on ne peut établir de lien de causalité entre l'aluminium ingéré par l'alimentation et des effets néfastes sur la santé. De nombreuses études suggèrent une relation entre la consommation d'aluminium et la maladie d'Alzheimer, mais là encore les résultats sont contradictoires. Des recherches supplémentaires sont nécessaires pour établir le risque lié à l'ingestion quotidienne d'aluminium par l'alimentation, l'eau et l'utilisation de produits pharmaceutiques. Les recherches futures devraient être menées sur des groupes plus sensibles au sein de la population comme les enfants et les consommateurs chroniques de produits pharmaceutique.

Mots-clés :

Aluminium, régime alimentaire, absorption, maladie d'Alzheimer, maladie de Parkinson

Abstract:

Aluminum is abundant in the environment and can also be found in most foods. To date, no convincing data has been found regarding the possible risk of ingesting aluminum through food, water and pharmaceuticals. This paper sought to review current literature to find evidence of the health effects of aluminum absorption in the diet in humans.

The review found that the evidence is contradictory and as such, there is no established causation between dietary aluminum and adverse health effects. Many studies suggest a relationship between aluminum consumption and Alzheimer's disease, but here again, the results are inconsistent. More research is needed to establish the risk of daily ingestion of aluminum through the diet, drinking water and the use of pharmaceuticals. Further research should be conducted on subpopulation groups, such as children, chronic pharmaceutical drug users and other vulnerable groups.

Keywords:

Aluminum, diet, absorption, Alzheimer's disease, Parkinson's disease

Introduction

When considering the health of an individual, it is important to include the external environment as it can have a large impact on their diet, activity, and exposure. Many metals and elements are present in the environment and make contact with humans during day-to-day life. These metals and elements can interact with the human body through various intake methods and sometimes negatively impact their health. One of the most abundant metals on Earth is aluminum (Encyclopedia of Earth, 2008), which accounts for 8% of the earth's crust (Health Canada, 1998). Aluminum has been shown to enter the human body predominantly through the oral route, as it is present in food, food additives, pharmaceuticals, utensils, and water (Greger & Sutherland, 1997).

Many studies have been conducted to assess the potential harmful health effects of daily ingestion of aluminum in humans. To date, aluminum has been linked to neurological and bone abnormalities (Greger & Sutherland, 1997), Alzheimer's and Parkinson's diseases (Greger, 1993), and cognitive impairments (Krewski et al., 2007). Furthermore, the process of 'Aluminum production' has received recent carcinogenic classification by the International Agency for Research on Cancer (IARC) (Krewski et al., 2007). Although most of these researchers have failed to demonstrate a robust link or cause, there is still concern regarding the effects of long-term aluminum exposure, especially to those individuals who consume more than the average quantity through their pharmaceutical regimens. This paper will outline the key findings in studies on dietary aluminum consumption to determine the human health effects of dietary aluminum and to establish whether it is a serious concern for humans. Firstly, absorption and distribution of orally ingested aluminum will be elaborated upon, and subsequently the human health effects will be explored.

Exposure

Orally ingested aluminum sources include food products, food additives, utensils and packaging items, water, and pharmaceuticals (Greger & Sutherland, 1997). Aluminum has been found in small quantities (i.e.: under 0.2 mg) in most foods (Greger & Sutherland, 1997). Certain plants such as tea leaves, however, accumulate more than 100 µg Al/g. This aluminum is often non-soluble, and therefore thought to be less of a concern for human health as the body does not as readily absorb it (Greger & Sutherland, 1997). According to certain American studies, the average adult consumes between 2-25 mg of dietary aluminum daily (Greger, 1993). Moreover, aluminum is present in food additives such as baking powder or flour, as aluminum compounds are sometimes used as pH adjusting agents (Krewski et al., 2007). A certain amount of aluminum is also present in utensils and packaging of foods such as cans. This is significant because, as described by Greger and Sutherland, "acidic foods cooked for long periods of time in aluminum pans can accumulate as much as 17 mg of aluminum in a 100 g serving" (Greger & Sutherland, 1997, p.441).

Water is another source of aluminum consumption, accounting for 5% of the total daily intake for the average adult (Health Canada, 2003). The presence of aluminum in drinking water is attributable to both suboptimal water purification techniques and excess natural occurrence (Becaria, Campbell, & Bondy, 2002). In Canada, water treatment plants use mostly aluminum sulphate compounds, although adequate water treatment should result in negligible amounts in the final drinking water. They are used "as coagulants to reduce organic matter, colour, turbidity, and microorganism levels" (World Health Organization, 2003). In addition to total concentration in water, solubility can affect the final plasma concentration of aluminum in someone exposed to it. The pH appears to be the most important factor aluminum solubility in water, as shown in Figure 1 (see Appendix). Both low and high pH levels encourage aluminum dissolution, increasing its absorption potential once in contact with humans (Agriculture and Agri-Food Canada, 2001).

The third known method of aluminum ingestion for humans is through pharmaceuticals. Aluminum is found in calcium supplements, sucralfate (an anti-ulcer agent), buffered aspirin, and aluminum-based phosphate binders. The latter can lead to the absorption of 10 g of aluminum per day when used by people with reduced renal function (Greger & Sutherland, 1997).

Absorption, Distribution, Metabolism, and Excretion

Considering these oral methods of aluminum entry into the human body, only about 1% of the aluminum ingested from food gets absorbed (Greger & Sutherland, 1997). Various factors intervene in the absorption process and much re-

mains unclear, requiring further research. It is known that the aluminum present in drinking water is more readily absorbed, though as mentioned earlier, it counts for a much lower amount (5%) of the daily intake compared to food (95%) (Health Canada, 2003). Within the body, factors such as the type of aluminum compound being ingested, the food itself, and the age and health status of the individual ingesting the items, specifically his or her kidney function, all account for the differing levels of absorption of aluminum (Health Canada, 2003). Certain studies have identified increased intestinal absorption in the elderly and immunocompromised individuals, leading to concerns about toxicity in these populations (Agriculture and Agri-Food Canada, 2001).

Aluminum may share absorptive pathways with calcium (Greger & Sutherland, 1997). A study by Cochran, Goddard, and Ludwigson (1990) on rats showed a small decrease in aluminum uptake in the presence of calcium channel blockers (Greger, 1993). However, their findings state that due to high levels of verapamil, a calcium-channel blocking agent used in their study, "the small reduction in rate of Al uptake which we observed cannot confidently be ascribed to direct closure of calcium channels to Al" (Cochran et al., 1990, p.293). This study did confirm, however, that aluminum uptake is energy dependant (Cochran et al., 1990). There is evidence that citric acid may also affect aluminum absorption. In patients taking citrate-containing pharmaceuticals concurrently with aluminum-containing pharmaceuticals, higher levels of urine and serum aluminum were detected (Greger, 1993). Three reasons are suggested by Greger to explain this increased absorption: firstly, citrate may increase the solubility of aluminum in the gut, making it easy to absorb; secondly, citrate may serve to co-transport aluminum into mucosal cells; and lastly, citrate may open epithelial tight junctions, allowing aluminum to pass out of the intestinal lumen (Greger, 1993).

The distribution of aluminum is better understood as accumulating mostly in bones and lungs (Krewski et al., 2007). Other affected areas are soft tissues (usually after intravenous fluid contamination), the spleen, liver, kidney, nervous tissues, muscles, and the heart (Greger, 1993). For orally ingested aluminum, however, the tissues mostly affected are the bones, liver and the blood itself (Greger, 1993). Once aluminum has entered the body, the mechanism by which it is metabolised is still not fully known. The routes of excretion are mostly from the kidneys, which accounts for 95% of elimination, and bile (Krewski et al., 2007). In short, much on the mechanism of aluminum pharmacokinetics in humans is unknown and there is a need for more research to be conducted in this field in order to better understand the compound's potential to affect human health.

Human Health Effects

Many human health effects that have been associated with aluminum are due to intravenous contamination. The most important health effect is dialysis encephalopathy, which can lead to tremors, convulsions, psychosis, and other related neurological problems (Health Canada, 2003). In addition, as previously mentioned occupational aluminum exposure has been shown to have carcinogenic effects. This paper will focus instead on the negative impacts linked to dietary aluminum, although these links have not yet been fully established. Health Canada's Review of Dietary Exposure to Aluminum states that "recent Canadian data suggests that current average aluminum intake through food does not pose an unacceptable health risk to Canadians" (Health Canada, 2008, p.3). The review goes on to state that despite the current status, many studies being conducted currently are showing results of adverse health effects in humans and animals with long-term aluminum exposure (Health Canada, 2008). This delay in conclusive results underlines the difficulty of regulating food and products and creating policies to protect citizens, as the federal government must have reasonable proof before it can act to restrict sales or consumption of a certain product but in waiting for this proof may be increasing the risk of toxicity in its citizens.

The many current contradictory studies make it difficult to assess whether there is sufficient evidence to establish that aluminum is unsafe for regular dietary consumption. A paper published by Yokel (1988) discussed the association between Alzheimer's disease (AD) and aluminum. Though the cause for AD is still unknown, this paper suggested that because the adverse human health effects of aluminum toxicity and the disease were similar (in that they both led to progressive central nervous system deterioration and dementia), there was possibly a link between the two conditions (Yokel, 1988). A Canadian paper published by McLachlan in 1995 clarifies that the relationship between aluminum and AD is not one of causation, but rather that "aluminum is a factor which promotes the expression of the dementia of AD, rather than the root cause of the di-

sease" (McLachlan, 1995, p.235). In 2002, another paper suggested that the disparities in the results regarding AD and aluminum toxicity may be due to methodology; specifically, in terms of how and where aluminum levels are measured in the body and how the data may be masked when analyzing bulk brain tissue in senile dementia patients (Becaria et al., 2002). Walton, in his paper published in 2009, shows a summary of 14 recent studies on the association between AD and aluminum content in drinking water (Walton, 2009a). Thirteen of these studies overlapped with a systematic review published by Flaten in 2001, which assessed aluminum as a risk factor for AD, and of these nine showed statistically significant positive relationships between aluminum content in drinking water and AD (Flaten, 2001). One of the studies from Walton's review, published in 1996, was conducted in Canada and found a significant risk of AD development associated with exposure to residential drinking water with an aluminum content of ≥100 µg/L (Becaria et al., 2002). Although ten reviewed studies in total showed statistically significant positive relationships, the other four found "no effect" (Walton, 2009a, p.1059). This emphasizes the inconsistent findings relating to risks of aluminum consumption in drinking water for humans. In more recent years, other health effects have similarly been linked to the intake of aluminum. Systematic reviews, which represent the highest methodological validity among scientific research, are important in establishing credible evidence around such uncertain relationships, and as more research is done additional reviews should be conducted.

Walton conducted another study in 2009, where three groups of young rats were fed diets containing low, intermediate, or high levels of aluminum reflecting the average human proportional consumption. They were then tested near end-of-life to determine their memory function. Rats with intermediate to high aluminum diets obtained lower memory test scores and had higher serum aluminum concentrations than those fed low aluminum diets (Walton, 2009b). Other studies have tested rats for different neurological effects, with one suggesting enhanced lipid peroxidation after aluminum exposure (Savory, Rao, Huang, Letada, & Hernam, 1999), and another showing impaired brain glucose utilization after aluminum exposure (Cho & Joshi, 1988). Additionally, aluminum has been linked to reproductive toxicities, where a mouse study showed that after three generations of consumption of aluminum-containing drinking water, second and third generation offspring had growth retardation (Ondreicka, Ginter, & Kortus, 1966).

Parenteral Nutrition

Although parenteral nutrition is not an oral route of aluminum ingestion, it does act as an alternative dietary method for patients with dysfunctional gastrointestinal tracts. Consequently, the health effects linked to aluminum exposure via this type of treatment will be explored further. In 1992, a study showed that people receiving parenteral nutrition had higher average plasma aluminum concentrations (0.59 µM) than those that did not receive such treatment (0.33 µM) (Bougle, Bureau, Voirin, Neuville, & Duhamel, 1992). Additionally, the concentration of aluminum in serum was higher in newborns receiving parenteral nutrition (37 µg/L) than those who were not (5.2 µg/L) (Sedman et al., 1985). Studies conducted in this field showed that the then typical solution of casein hydrolysate contained more aluminum than similar lipid solutions (Yokel, 1988), resulting in practice changes by many institutions. As a result of these findings, many governments also set limits for the quantity of aluminum in parenteral solutions. For example, in the United States the U.S. Food and Drug Administration permits a maximum of 25 µg Al/L in large volume parenterals (Bougle et al., 1992).

The adverse health effects linked to parenteral nutrition contaminated with aluminum are elevated stainable bone aluminum and osteomalacia (Ott et al., 1983). In rats, parenteral nutrition formula containing aluminum led to an accumulation of the element in the liver and portal inflammation causing hepatobiliary dysfunction (Demircan et al., 1998). Of the population at risk for adverse health effects relating to this alternative form of feeding, neonates are especially susceptible due to their lower ability to excrete aluminum, and should thus be a focus of research to understand more about aluminum's pharmacokinetics and dynamics (Willhite et al., 2012).

Conclusion

Much of the information from studies concerning human health effects of dietary aluminum is contradictory or only shows a possible link, and there is currently no established proof of interaction or causation. Part of the reason for this lack of research is the ethical dilemma of human testing. Many studies have been conducted on animals for this reason, as it can be scientifically relevant to not only monitor but manipulate aluminum exposure throughout life. Until more evidence can be found regarding aluminum's possible toxic effects on human health, its consumption should

be kept to a minimum. This is especially logical as there is no risk associated with aluminum deficiency; as Greger describes, "no conclusive evidence suggests that aluminum is essential for growth, reproduction, or survival of humans or animals" - and therefore it should be removed from our diet, pharmaceuticals and food additives (Greger, 1993, p. 56). Supplementary research should also be conducted in subpopulations such as children, patients taking antacids or other aluminum-containing pharmaceutical drugs daily, patients with reduced renal functions, and patients on parenteral nutrition regimens to see if these groups might have a greater risk of suffering from adverse health effects.

Considering the multiple studies showing a link between aluminum consumption in drinking water and AD, further extensive research should be completed on this topic as well. It may also be important for the Canadian and other federal governments to consider an alternative aluminum salt-based water treatments, seeing as their safety has not been reasonably established. In short, dietary aluminum is a human health concern in today's society as it is omnipresent in our daily lives, and many studies have found it to be a risk to neurological, bone and reproductive health. Until we can be sure that these studies' findings were false or showed correlation but not causation, aluminum should not be considered a safe metal to ingest and Canadian policies should reflect this.

Appendix

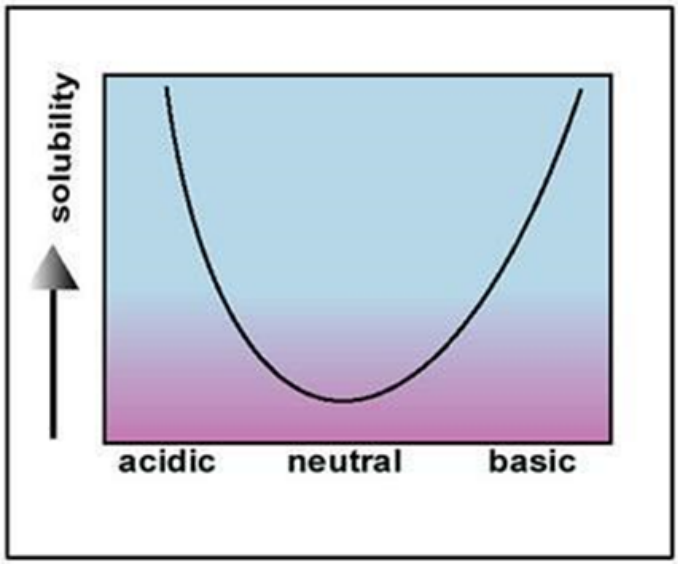

Figure 1 Solubility of aluminum in water according to pH level (Agriculture and Agri-Food Canada, 2001).

References

Agriculture and Agri-Food Canada. (2001). Aluminum and health. Retrieved from http://www.pfra.ca/doc/Water%20Treatment/aluminum%20and%20health.pdf

Becaria, A., Campbell, A., & Bondy, S. C. (2002). Aluminum as a toxicant. Toxicology and Industrial Health, 18(7), 309-320. doi: 10.1191/0748233702th157oa

Bougle, D., Bureau, F., Voirin, J., Neuville, D., & Duhamel, J. F. (1992). A cross-sectional study of plasma and urinary aluminum levels in term and preterm infants. Journal of Parenteral and Enteral Nutrition, 16(2), 157-159. Retrieved from: http://www.ncbi.nlm.nih.gov/pubmed/1556812

Cho, S., & Joshi, J. G. (1988). Effect of long-term feeding of aluminium chloride on hexokinase and glucose-6-phosphate dehydrogenase in the brain. Toxicology, 48(1), 61-69.

Cochran, M., Goddard, G., & Ludwigson, N. (1990). Aluminum absorption by rat duodenum: Further evidence of energy-dependent uptake. Toxicology Letters, 51(3), 287-294.

Demircan, M., Ergün, O., Coker, C., Yilmaz, F., Avanoglu, S., & Ozok, G. (1998). Aluminum in total parenteral nutrition solutions produces portal inflammation in rats. Journal of Pediatric Gastroenterology Nutrition, 26(3), 274-278.

Encyclopedia of Earth. (2008). Health effects of aluminum. Retrieved from http://www.eoearth.org/view/article/51cbedf87896bb431f69527b/

Flaten, T. P. (2001). Aluminium as a risk factor in Alzheimer's disease, with emphasis on drinking water. Brain Research Bulletin, 55(2), 187-196.

Greger, J. L. (1993). Aluminum metabolism. Annual Review of Nutrition, 13(1), 43-63. doi: 10.1146/annurev.nu.13.070193.000355

Greger, J. L., & Sutherland, J. E. (1997). Aluminum exposure and metabolism. Critical Reviews in Clinical Laboratory Sciences, 34(5), 439-474. doi: 10.3109/10408369709006422

Health Canada. (1998). Aluminum. Retrieved from http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/aluminum/index-eng.php

Health Canada. (2003). Aluminum and human health. Retrieved from http://www.porcupinehu.on.ca/Inspection/documents/aluminum_02_16_2007e.pdf

Health Canada. (2008). Health Canada review of dietary exposure to aluminum. Retrieved from http://www.hc-sc.gc.ca/fn-an/securit/addit/aluminum-eng.php

Krewski, D., Yokel, R. A., Nieboer, E., Borchelt, D., Cohen, J., Harry, J., ... & Rondeau, V. (2007). Human health risk assessment for aluminium, aluminium oxide, and aluminium hydroxide. Journal of Toxicology and Environmental Health, Part B: Critical Reviews, 10(Supp. 1), 1-269. doi: 10.1080/10937400701597766

McLachlan, D. R. C. (1995). Aluminum and the risk factor for Alzheimer's disease. Environmetrics, 6(3), 233-275. doi: 10.1002/env.3170060303c

Ondreička, R., Ginter, E., & Kortus, J. (1966). Chronic toxicity of aluminium in rats and mice and its effects on phosphorous metabolism. British Journal of Industrial Medicine, 23(4), 305-312.

Ott, S. M., Maloney, N. A., Klein, G. L., Alfrey, A. C., Ament, M. E., Coburn, J. W., & Sherrard, D. J. (1983). Aluminum is associated with low bone formation in patients receiving chronic parenteral nutrition. Annals of Internal Medicine, 98(6), 910-914.

Savory, J., Rao, J. K., Huang, Y., Letada, P. R., & Hernam, M. M. (1999). Age-related hippocampal changes in Bcl-2: Bax ratio, oxidative stress, redox-active iron and apoptosis associated with aluminum-induced neurodegeneration: Increased susceptibility with aging. Neurotoxicology, 20 (5), 805-817.

Sedman, A. B., Klein, G. L., Merritt R. J., Miller, N. L., Weber, K. O., Gill, W. L., ... & Alfrey, A. C. (1985). Evidence of aluminum loading in infants receiving intravenous therapy. New England Journal of Medicine, 312(21), 1337-1343.

Walton, J. R. (2009a). Brain lesions comprised of aluminum-rich cells that lack microtubules may be associated with the cognitive deficit of Alzheimer's disease. NeuroToxicology,30(6), 1059-1069. doi: 10.1016/j.neuro.2009.06.010

Walton, J. R. (2009b). Functional impairment in aged rats chronically exposed to human range dietary aluminum equivalents. NeuroToxicology, 30(2), 182-193. doi: 10.1016/j.neuro.2008.11.012

Willhite, C. C., Ball, G. L., & McLellan, C. J. (2012). Total allowable concentrations of monomeric inorganic aluminum and hydrated aluminum silicates in drinking water. Critical Reviews in Toxicology, 42(5), 358-442. doi: 10.3109/10408444.2012.674101

World Health Organization. (2010). Aluminum in Drinking -water. Retrieved from http://www.who.int/water_sanitation_health/publications/aluminium/en/ WHO reference number: WHO/HSE/WSH/10.01/13

Yokel, R. A. (1988). Aluminum and alzheimer's disease: Should we worry? Journal of Pharmacy Practice, 1(2), 118-127. doi: 10.1177/089719008800100207