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Aluminium Toxicity Affects Different Organisms: A Mini Review

G. Kondaiah [a++*], U. Srineetha [b#], D. Veera Nagendra Kumar [c#] and C. Narasimha Rao [d#]

[a] Yogi Vemana University, Kadapa, Andhra Pradesh, India.
[b] Department of Zoology, Government Degree College for Women, Pulivendula, (Affiliated to Yogi Vemana University, Kadapa), Andhra Pradesh, India.
[c] Department of Zoology, Government Degree College for Men (A), Kadapa, (Affiliated to Yogi Vemana University, Kadapa), Andhra Pradesh, India.
[d] Department of Zoology, Government Degree College, Mydukur, (Affiliated to Yogi Vemana University, Kadapa), Andhra Pradesh, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aluminium is the third most common metal in the earth's crust. It can exist in two ways, such as natural and anthropogenic, and be used as cooking utensils. It doesn't show any biological function in the organism's body. However, it is a contaminant element. It leads to aluminium toxicity in different organisms. The major common carrier for aluminium is water. Plants with roots, fish, and other tap water organisms are exposed to possible aluminium (Al) toxicity. Once this metal enters

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[++] *Research Scholar;*
[#] *Lecturer;*
**Corresponding author: Email: kondumsc@gmail.com;*

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the body, it exhibits toxic effects on different vital organs and organ systems, such as the central nervous system, respiratory system, liver, blood circulation, kidney, and reproductive systems. It is also known as a neurotoxic representative because this metal accumulates in the brain tissue of Alzheimer's disease (AD). This toxicity is measured by different factors and is divided into acute and chronic conditions. The toxicity of aluminium metal depends on its concentration, route of exposure, and period of exposure. The present review describes the analysis of aluminium toxicity in different organisms with reference to definition, sources, and health effects.

Keywords: Aluminium toxicit; Alzheimer's disease; acute; chronic conditions; kidney.

1. INTRODUCTION

Aluminium (Al) was first identified in 1827. It is widespread in the environment, constituting approximately 8% of the earth's crust. After oxygen and silicon, it is the third most frequent element. It is a soft, nonmagnetic, ductile, and silvery-white metal. Since the early 20th century, Al has been widely used as the chief cooking utensil. It is also a lighter metal used for aircraft, electric cables, etc. Al will mix with the food during the cooking process because of its low melting point. Cooking with aluminium utensils results in aluminium being transferred into the foods. Human exposure to aluminium comes from food and drinking water as well as from pharmaceuticals [1,2].

Al is a versatile metal with several properties and manufactured utensils are commonly used in developing countries and India for the purpose of household cooking, aluminium foil used for cooking as well as packaging of food. It is combined with oxygen to form a colorless aluminium oxide which blocks further oxidation whenever exposed to air. It is used in different alloys with other metals such as magnesium, zinc, and copper [3,4].

However, it is a toxic metal that doesn't show any physiological role in the organism body but may produce adverse physiological effects. It is exposure into the environment through natural and anthropogenic ways. The natural ways are water, soil, air and anthropogenic (man made) ways are industrial processes, mining, drugs, cosmetics and food additives [5].

The environment cannot be destroyed by Al, but it can change environmental structure or separate from particles. Al particles in the air settle to the ground or washed out by rain. Levels of Al in the air on an average range from 0.005 to 0.18 micrograms per cubic meter, depending on location.

Most aluminium containing compounds do not dissolve in water and turns into acidic or alkaline. The concentration of Al in natural water bodies such as ponds, lakes, streams is generally below 0.1 mg/L.

In the aquatic environment, accumulation of Al compounds affects the aquatic vertebrates, especially fish poisoning. Slaninova et al. stated that, Al metal enters into the fish body through the contaminated water, and shows histopathological characters in gill tissue necrosis, parenchymatous tissues of the kidney, liver, and spleen [6]. This contaminated fish damages the food chain and ecosystem. Recently invented aluminium materials, which hamper life exposure in environment both aquatic life and terrestrial, including the human has consistently been linked to various diseases like Alzheimer's, myocardial necrosis, and kidney failure.etc.

This review provides an analysis of 'aluminium toxicity affects different organisms' with reference to definition, sources, health effects from different living organisms to humans and their organs are critically evaluated.

2. METHODOLOGY

This review summarizes and analyses primary information created and provided by other academic and professional researchers who studied aluminium metal and its toxic effects on different living organisms. A literature review was conducted using search terms such as, aluminium metals, aluminium toxicity, toxicity measurement, sources, and organ diseases on organisms in relevant studies on PubMed, Google Scholar, EMBASE, Scopus, Science Direct, Medline, NCBI, and Web of Science databases. This review paper analyzed a total of 28 research articles published in reputed journals.

2.1 Sources of Aluminium

Al elements are found in the environment through both natural and anthropogenic processes. The natural sources are water, soil, air, and food. It is present in drinking water and water treatment methods. Water provides only about 1% of the normal daily human intake. Aluminium can exist in water and is affected by different parameters, i.e., pH, which regulate the forms of aluminium that are available in an aqueous environment (World Health Organization, 2003) [4]. Water is the daily Al concentration average: 70 µg/l; exposure: 100 µg; and absorbed by 0.005 (µg/kg)[a]. Aluminium is present in the air from volcanic eruptions as well as from weathering processes. Air emissions from the aluminium production process, coal combustion, mining, waste incineration, and motor vehicle exhaust all contribute to higher aluminium concentration in the air [5]. The daily concentration of air is is 0.2 µg/m3, exposure is 4 µg, and absorbed by 0.001- 0.0001 (µg/kg)[a]. It occurs naturally in foods of both plant and animal origin. From plants, herbs, flour, salt, cocoa foods containing aluminium. The anthropogenic (manmade) sources of aluminium are cookware, toothpaste, antiperspirants, vaccination, and some drugs such as buffered aspirin and antacids. Aluminium containing food additives belongs to secondary anthropogenic sources; they have a decisive influence on the whole aluminium concentration in foodstuffs. Aluminium is used to prepare utensils, aeroplanes, beverage cans, pots, roofing equipment, and foil [4].

2.2 Measurement of Toxicity

The toxicity of a given aluminium compound can be described by a direct limitation, which is correspondingly easy to measure. The results of toxicity measurements depend on many factors, such as the exposure time, the dose administered, the measurement technique, and the nature of the biological object being affected. With regard to the exposure time, toxicity can be divided into two types: acute and chronic [6].

Acute toxicity is distinct within a relatively short time interval after toxicant exposure, i.e., a short and few minutes to several days. It is generally caused by a single exposure to a chemical and is used as an indicator of a poisoning event or as an appropriate measure of the toxic capability of a substance. It is confined by a dose-response relationship or by a dose-response curve. The dose-response relationship is a relationship between the dose and the incidence of a defined biological effect in an exposed population, generally expressed as a percentage.

Acute toxicity is measured by the different values and characteristic features. The values are LD50, LC50, ED50, EC50. Chronic toxicity is exhibited by prolonged exposure, normally to small quantities of a toxicant that the exposure times are frequently a notable part of the estimated lifetime of the organism.

Table 1. Sources of aluminium metal in the environment

Types of source	Details of aluminium	Al concentrations
Plant source	➢ potatoes, and spinach, vegetables and fruits	5.00 -10.00 mg/kg
	➢ cofee, tea, spices, and herbs	>10 mg/kg
Animal source	➢ Milk, eggs, seafood,	5.00 -10.00 mg/kg

Source: Stahl et. al [7]

Table 2. Acute and chronic clinical manifestations

Acute	Chronic
Confusion	Pulmonary toxicity
Delirium	Haematologic toxicity
Seizures	Skeletal toxicity
Myoclonus	Neurologic toxicity

Source: Carroll D et al. [8]

3. ALUMINIUM TOXICITY EXPOSURE IN DIFFERENT ORGANISMS

Aluminium toxicity is responsible for the toxic effects on different living organisms. About 5 to 10mg of aluminium enters an organism's body through different sources such as water, food, occupational industries and so on. However, in the following sections, the paper discusses the affects of aluminum toxicity on different organisms and human health based on several cases reported in the literature.

3.1 Aluminium Toxicity Exposure in Fish

Aluminium enters into the water through the aluminium processing industry. Then aquatic organisms uptake this water turns into bioaccumulation. The bioaccumulation occurs when an organism absorbs a substance faster than it can be lost or eliminated by catabolism and excretion. Aluminium metal particles accumulate in the fish body, and are exposed to the environment through lipid layer uptake of water. An increase in aluminium concentrations in water causes acidification, resulting in organ damage in aquatic species, especially fish. Physiological and histological alterations are also observed in different fish species exposed to Al. In fish species, the most important Aluminium sensitive organ is the gill. And other organs, such as liver, muscle, brain, heart, and kidney, can also be affected. Al toxicity causes gill membranes through the displacement of Ca by this ion, which results in a passive effiux of electrolytes.

Slaninova et al. stated that, a significant reduction in the growth of fish was observed with concentrations of Al as low as 0.52 mg/l. Miri et al. Reported that, some tissue enzymes of the gills, liver and muscles in the common carp (Cyprinus carpio) affected by aluminum [6]. Typical symptoms are respiratory distress and a low pH as a result of the combined respiratory and metabolic acidosis. The respiratory epithelium of filaments with differing degrees of dystrophic changes, including excessive vacuolisation, swelling, and disorganisation of cells of the lamellar epithelium and filling the space between filaments with detached and degenerated epithelia [9,10].

The histopathology characters are gill tissue necrosis, large eosinophilic cells with granulated cytoplasm in large clusters in the respiratory epithelium, mainly at the base of gill filaments. Cellular inflammatory infiltration is formed in the gill arch epithelium.

3.2 Aluminium Toxicity Exposure in Husbandry Animals

Al toxicity occurs in agricultural animals such as cattle, sheep, and poultry birds. Generally, cattle and sheep feed on plants that accumulate high levels of aluminium, and in poultry feed contain aluminium from contaminated feed ingredients. The symptoms are decreased feed intake, disturbances in mineral metabolism, including reduced phosphate absorption and reduced efficiency in converting feed to body weight gain, reduced bone mineralization, hypercalcemia, and accumulation of aluminium in body tissues [11].

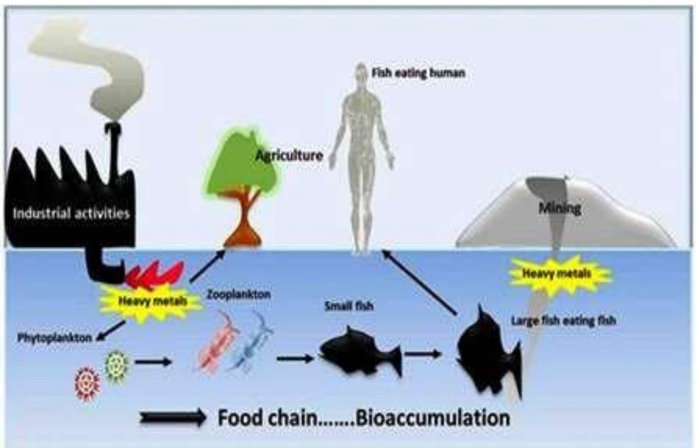

Fig. 1. Bioaccumulation of fish
Source: Choudhary et al .[10]

3.3 Aluminium Toxicity Exposure in Plants

Aluminium enters into the plant's body through the soil. Plants are uptake through roots. This metal toxicity affected different parts of the plant. G.R. Rout et al. Stated that, aluminium uptake and transport, cytogenetic effect and biochemistry of aluminium phytotoxicity are elucidated. Roots and leaves are affected by Al toxicity [12]. Majority of the plants have low levels of Al. But some plants, such as tea leaves, marshmallow root, have a high level of Al. Typically, the intake of tea to the body Al absorbed between 0.2-1.5%. Marshmallow root has 19.28 mg per ounce. The roots are characteristically stubby and brittle, root tips and laterals thicken and the tum browns; the epidermis disintegrates.

3.4 Aluminium Toxicity Exposure in Human Beings

Nowadays, the aluminium metal annual global demand is 11 kg, and the metal must be cast for every person on Earth. This aluminium, extracted by industry from its inert edaphic stores, has the potential at least to impact upon biota including humans [14]. Different ways are present to exposure of aluminium, nose, skin, aerosol, dite, etc. Drinking water provides about 1% of normal daily Al intake.Al bioavailability from water is greater than from food, based on the presence of ligands in food that might complex Al, to possibly inhibit its oral absorption. The most recent analysis shows that humans are directly exposed to Al at a rate of 0.1%. The daily exposure of aluminium averages 30 mg [15]. Similarly, our exposure to Al would have been 1 mg per day in the year 1950, and it will increase to 100 mg per day by the year 2050. The Al intake by airborne Al-containing particles, drinking water, food and pharmaceuticals. Usually, Al toxicity affects different body organs, such as the brain, heart, muscles, bone, liver and kidney.

3.4.1 Al toxicity affects brain health

Al deposits in the brain occur mainly through inhalation. Al enters the nasal cavity and lungs and, in due course, is absorbed into the blood stream. N. Hadrup et al. stated that, aluminium oxide concentration causes a higher frequency of headache, vertigo, emotional irritability, concentration difficulty, insomnia, mood lability, anxiety and fear. Ikechukwu et al. reported that, Alzheimer's disease, autism, osteoporosis, diabetes mellitus, inflammatory bowel disease are caused by aluminium toxicosis. Some other symptoms are disorientation, a changed mental state, anxiety, and acute hypoxic encephalopathy [16,17,7].

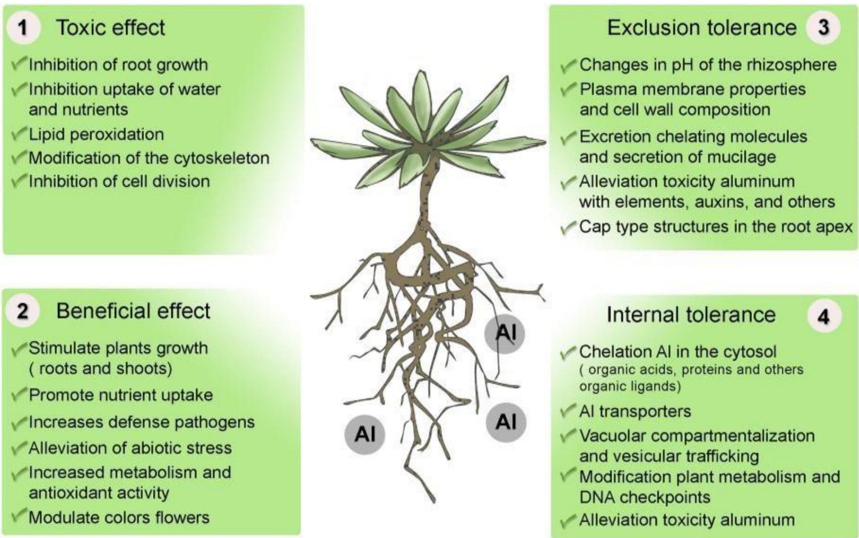

Fig. 2. Effect of aluminum on plants and mechanisms of tolerance to stress by aluminum. (1) Toxicity of Al in plants. (2) Beneficial effect of Al in some taxas, mainly species adapted to acid soils. (3) Mechanisms of exclusion, resistance or alleviation of Al uptake, and (4) Mechanisms of internal tolerance to stress by Al in plants

Source: Bojorquez-Quintal et al. [13]

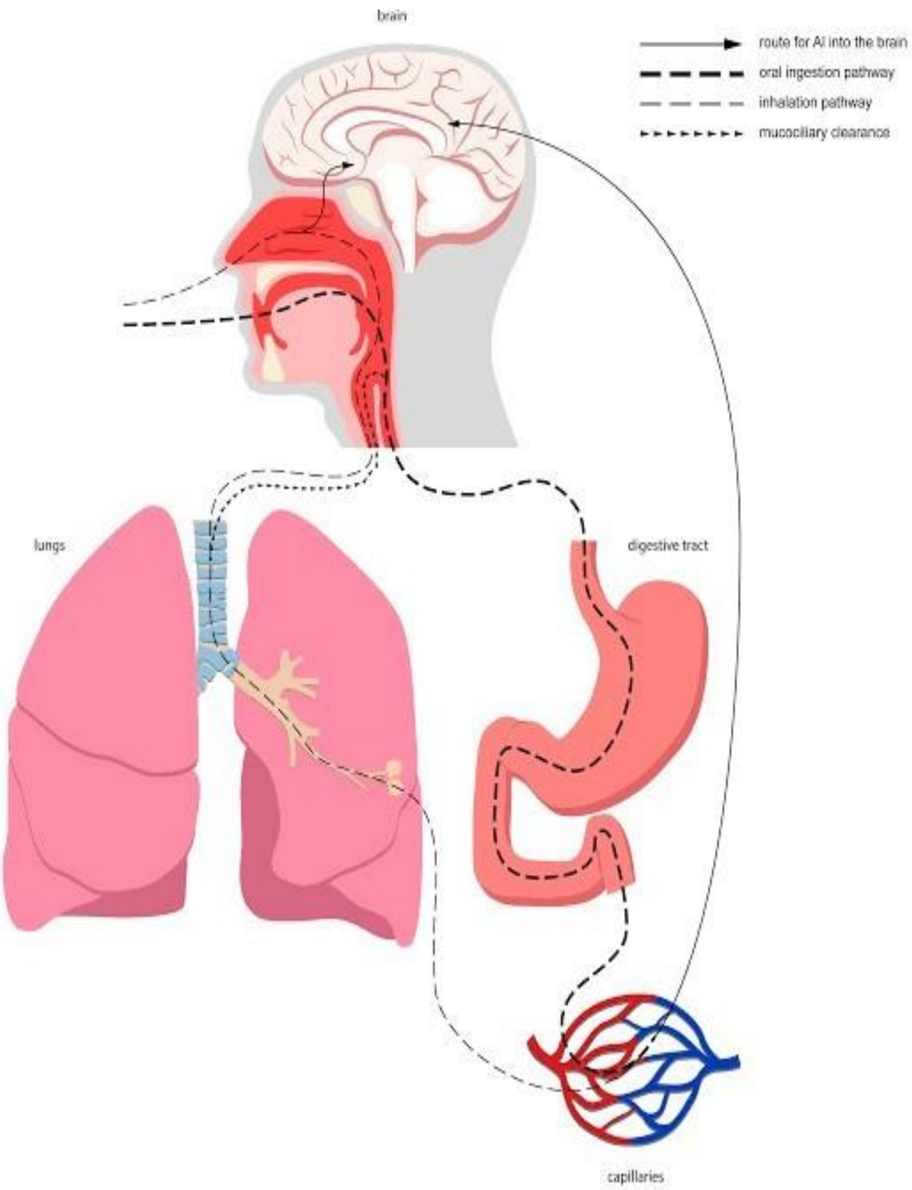

Fig. 3. Main routes for Al into brain
Source: Brylinski et al.[18]

3.4.2 Al toxicity affects heart health

Al phosphide (ALP)intoxication causes myocardial necrosis, left ventricular apical thrombus, toxic myocarditis, myocardial hypokinesia, left ventricular thrombosis and myocardial dysfunction occur [19]. Saad et al. stated that, aluminium chloride accumulation in the heart causes congestion of blood vessels, interfibrillar edema, hemorrage and zenker's degeneration of myocardium [20].

The cardiovascular effects caused by toxicosis include dysfunction of the myocardium, congenital heart defects, cardiovascular thrombosis, and inflammation.

3.4.3 Al toxicity affects bone health

The majority of the aluminium is incorporated into the bones. Aluminium poisoning obstructs the normal accumulation of Ca^{2+} and phosphate in bones. This intervention occurs due to bone loss and fragility. Other diseases are osteomalacia, osteoporosis, anemia, rickets, and hungry bone syndrome. And also Multifocal osteonecrosis linked with chronic occupational exposure to aluminium. Jeno I. Sebes reported that, aluminium intoxication causes osteoporosis, multiple fractures, and hypercalcemia [21,8,22,23].

3.4.4 Al toxicity affects liver health

The liver is a metabolism organ and plays an important role in toxicity and maintains the energy level. Aluminium deposition in the liver is higher than in bones. In the liver induced Al causes oxidative stress, immune cell activation, obesity, and type 2 diabetes. Cell death by necrosis, or apoptosis, and dysplasia from genetically driven cell growth abnormalities. Al toxicosis causes cellular degeneration occurring in nervous tissue, liver and kidney. The hepatic lesions also occur through Al toxicity, causing changes in metabolism such as hyperglycaemia, hypoproteinaemia, hyperlipidaemia, hypercholesterolaemia and hypertriglyceridaemia[24].

3.4.5 Al toxicity affects kidney health

The Kidney effect due to aluminium is still an interesting problem. The kidney is one of the major organ exposure to aluminium. Generally, aluminium is excreted by the kidneys and accumulates in renal tubules. In the kidney, Al may cause a sudden loss of kidney function due to the addition of the tubules, which causes tubular necrosis, also called acute kidney injury. At the same time, impaired function effects are glomerular sclerosis, tubular damage, encephalopathy, and interstitial fibrosis [25,26].

Table 3. Exposure routes and aluminium concentrations

Exposure routes	Aluminium concentration
Breast milk	0.74 L/ day
Air	2 m^3/ day

Source: Vaccine Evidence

Table. 4. Different clinical presentations of aluminium toxicity

S. No	Organism	Affected organs	Symptoms	References
1.	Plants	Leaves, Roots	Inhibition of root elongation, blockage of cell division, roots are stubby and brittle, etc	G.R. Rout et al. [13]
2.	Fish	Gills	Gill tissue necrosis	Slaninova et al.[9]
3.	Cattle and sheep	Muscles and bones	Reduced body weight, reduced bone mineralization, hypercalcemia,	Biocyclopedia.[12]
4.	Poultry birds	Reproductive organs	Decreased egg production and fertility	Biocyclopedia.[11]
5.	Humans:			
		Brain	Alzheimer's disease, Parkinson's disease, multiple sclerosis and autism, Headache, irritability.	Yokel RA et al.[17]
		Heart	Myocardial dysfunction, cardiovascular thrombosis.	Saad et al.[20]
		Bone	Fragility, osteomalacia, osteoporosis, anemia, rickets,	Gordon L.K et al.[21]
		Liver	Hypoproteinaemia, hyperlipidaemia, hypercholesterolaemia,	Feibo Xu et al.[23]
		Kidney	Tubular necrosis, interstitial fibrosis, glomerular sclerosis,	Shigematsu et al.[25]

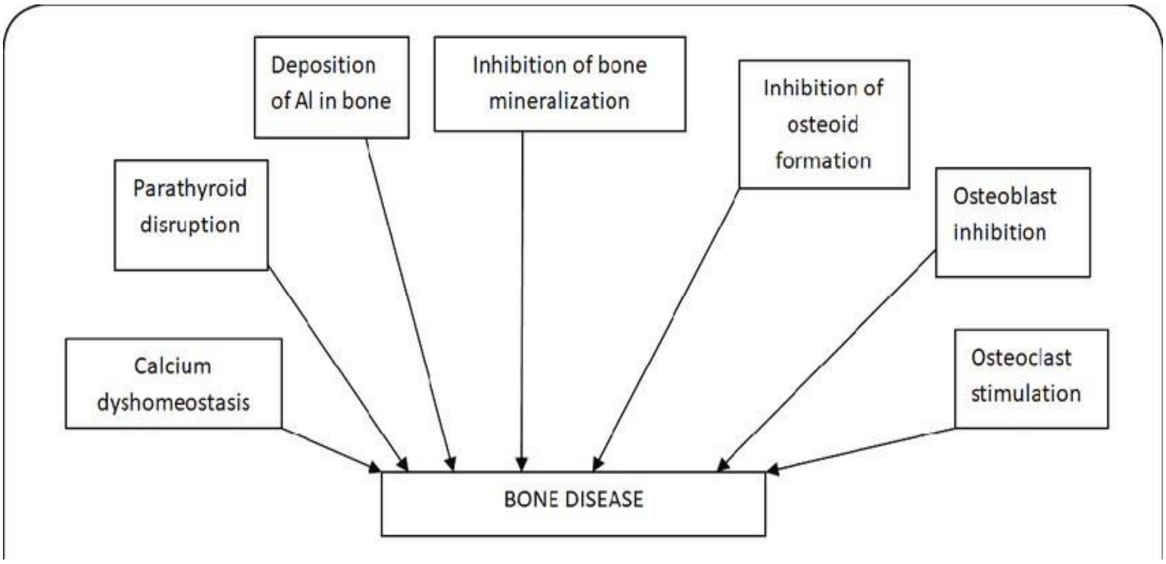

Fig. 4. Pathogenesis of bone disease in aluminium toxicosis.
Source: Ikechukwu et al.[16]

3.5 Exposure to Aluminium Toxicity in Infants and Children

In infants, aluminium may enter into two ways by adapted formulas or breastfeeding and by vaccines. The greatest risk of aluminium exposure via parenteral nutrition has been shown to have long-term effects. Aluminium concentrations are higher in humans. Breast milk contains an average of 23.9 mcg/L, and an avarage of o.74 L/day, which results in long-term health concerns such as Alzheimer's disease [2,28].

6. CONCLUSION

Results of this study indicate that aluminium metal increases the risk of exposure and subsequent health hazards. It is highly recommended that we should avoid or reduce exposure to aluminium and its contaminated sources such as foods, water, utensils, drugs. A number of research gaps need to be filled to better assess the risk of aluminium toxicity in the environment and society and inform management actions because aluminium damages the food web through the food chain in the ecological environment. Further, future research should be conducted on ways to reduce the discharge of aluminium metals from different sources into the environment and to protect the ecosystem from their hazardous effects.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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