

Neurological Impact of Zinc Excess and Deficiency in Vivo

ABSTRACT

Zinc is an essential mineral that can cause pathological effects whether in excess or deficiency. Zinc is a component for over 250 enzymes and is required for cell growth, cell division, and cell function. Zinc is found in muscle and bones, with the prostate, liver, skin, and kidney having detectable levels of zinc. However, zinc present in excess or deficiency can cause significant pathology in patients that include deleterious effects neurologically. Zinc in excess in vivo can focal neuronal pathology, while zinc deficiency can bring about mental lethargy, neuropsychiatric disorders, and reduced nerve conduction. Zinc is assimilated within the body by oral ingestion, dermal exposure, and pulmonary inhalation. Although not generally viewed as a cause of cancer, studies suggest that zinc is associated with progression of prostate malignancy. Toxic levels of zinc have been shown to induce lethargy, neurotoxicity, and gliotoxicity. High levels of zinc cause neuronal death in cortical cell tissue culture. Zinc is found to accumulate following the death of neurons in global ischemia. Therefore, zinc deficiency or excess is a significant clinical concern.

Keywords: zinc, toxic metals, vitamins, minerals

1. AN ESSENTIAL MINERAL

Zinc is an element found in-group 12 of the periodic chart and is a transition metal (any element in the d-block of the periodic table). Zinc is an essential mineral, one of a total of 16, which includes [1]: calcium, phosphorus, potassium, sulfur, sodium, chloride, magnesium, iron, zinc, copper, manganese, iodine, and selenium, molybdenum, chromium, and fluoride. There are two types of minerals: macro-minerals and trace minerals. Macro-minerals are minerals required for normal health in larger amounts than trace minerals. Macro-minerals include calcium, phosphorus, magnesium, sodium, potassium, and chloride. Zinc is an important mineral for many organisms and is known to be a component of more than 250 enzymes and a large number of proteins [1]. Therefore, zinc is profoundly important for normal human health.

Of all the zinc found in the human body, almost 90% are located in the bones and muscles of individuals [1]. The oral consumption of zinc is followed by absorption in the small intestines, followed by dissemination throughout the body, carried by serum where it is bound to proteins [1].

Having noted the importance of zinc for human nutrition and health, it is necessary to address the reality that zinc deficiency or significant excess in the body results in pathological conditions. Zinc can play a strong role in neuronal death and participate in toxic events on the cellular level [1]. Zinc is believed to be associated with the regulation of

apoptosis (death of cells that occurs as a normal and controlled part of an organism's development) at the cellular level [1].

2. ZINC IN THE HUMAN BODY

Almost 90% of the total amount of zinc found in the body (up to 3 grams total) is located in the bones and muscles [1]. Zinc is also found in the gastric intestines, brain, pancreas, skin, stomach, and kidney (see Figure 1) [2, 3]. Once in the serum, zinc is bound to proteins such as transferrin, α -microglobulin, and albumin [1].

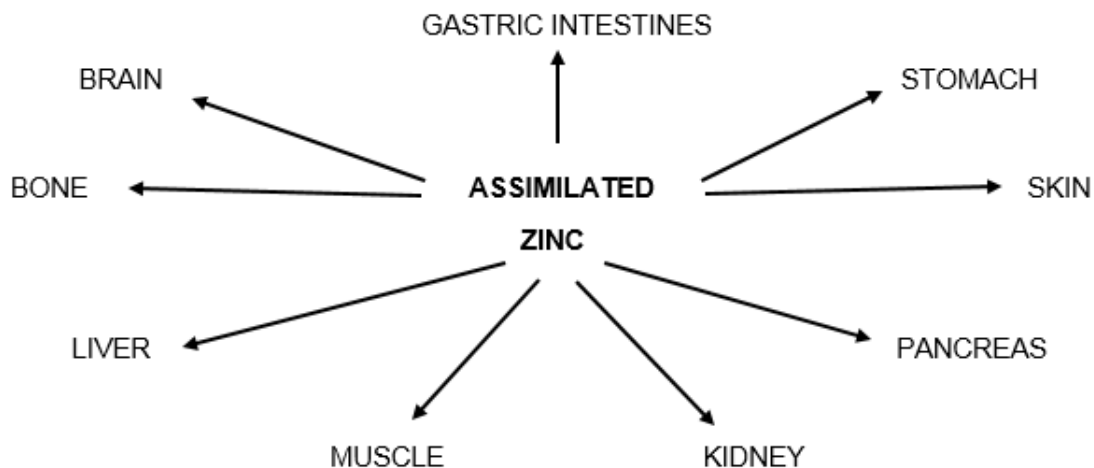


Fig. 1. Disposition of zinc in the human body. Zinc is found in numerous organs, including the brain, bones and muscle.

Within the cell itself, it is generally accepted that 50% of zinc present will be in the cytosol with somewhere from 30% to 40% contained in the nucleus [4]. The remaining balance is localized in the membranes [4]. In these locations, zinc plays an important role in nucleic acid and protein metabolism, as well as cell growth, function, and cell division [5]. Interestingly, the cellular zinc component is thought to play some role in homeostatic control that avoids the assimilation of excess zinc [1].

3. ZINC ASSIMILATION, NEUROLOGICAL AND OTHER EFFECTS

The assimilation of zinc into the human body can be accomplished by three pathways. These three pathways are inhalation, oral ingestion, and absorption through skin [6]. The eventual effects, as a result of each type of assimilation, will be upon specific portions of the body in these pathways [6].

Although there are pathological results of excessive uptake or deficiency, the oral ingestion of adequate zinc in nutrition is important for normal health [1]. The oral consumption of excessive amounts of zinc will quickly bring about noticeable nausea, vomiting, abdominal pain, and eventual anemia [7]. Subsequent effects originating from the central nervous system will include lethargy (pathological state of unresponsiveness, inactivity, and dizziness) [7]. Further studies have shown that excessive oral ingestion will bring about overt symptoms such as fatigue and lethargy [8].

Pulmonary inhalation of continuous/excessive amounts of zinc is shown to cause pathological issues. Inhalation of zinc in the form of industrial originated zinc oxide will cause shakes and chills, sometimes referred to as metal fume fever or zinc shakes (illness primarily caused by exposure to chemicals such as zinc oxide) [9]. Galvanization (applying zinc to other metals to prevent rust) is a process that can result in aerial exposure of zinc [1]. Particle sizes of less than 1 micrometer can effectively introduce troubling levels of zinc into the body, with these exposures primarily originating from industrial settings [10]. Symptoms noticeable include fatigue, nausea, fever, chest pain, cough, dyspnea (difficult breathing), and muscle soreness [11].

Concerning assimilation through the dermal layers, it is known that zinc is a common component of various topical treatments of various conditions, including of wounds that cause breaks within the skin [12]. However, the extent of zinc absorption is influenced by the pH of the skin, chemical speciation, and amount of zinc applied from the medicament [13]. Overall, it is generally accepted that exposure to zinc through dermal pathways does not constitute a significant pathological risk [1].

Interestingly, the excess exposure to zinc derived from denture adhesives can induce copper deficiency leading to neurological symptoms involving walking and balance [14]. Unfortunately, recovery from these neurological symptoms looks to be limited in extent and efficacy [14]. Alarmingly, other investigators have reported even more severe results of excess zinc exposure from denture fixative creams that include serious neurological effects such as degeneration of the spinal cord, crippling nerve damage such as human swayback disease, as well as bone marrow suppression [15]. Swayback disease caused by excess zinc that induces a copper deficiency brings about neurological manifestations, including myelopathy (disease of the spinal cord), a spastic gait, and prominent sensory ataxia (loss of control) [15]. Copper deficiency, induced by zinc exposure in denture creams is shown to cause serious neurological disease [16].

Therefore, the assimilation of excess zinc as well as the deficiency thereof- induces various significant neurological related health maladies, these summarized in Table 1. These include lethargy, effects upon focal ability, and psychiatric conditions [1]. There are other notable health related risks associated with zinc assimilation.

Table 1. Effects Caused by Zinc Deficiency and Substantial Excessive Presence

Condition/Pathology	
Zinc Deficiency	Zinc Substantial Excess
Reduction of Nerve Conduction	Mental Related Lethargy
Lethargy Due to Mental Effects	Reduction of Focal Activity
Pathology of Neurosensory Ability	
Pathology of Psychiatric Ability	

Certain metals have been associated with carcinogenicity (i.e. nickel, chromium) but zinc is overall not accepted to be a causative factor for cancer [1]. However, other studies of prostate adenocarcinoma, and particularly those monitoring the level of zinc in the surrounding tissues, indicate the potential involvement of zinc in the progression of prostate malignancy [17, 18].

Even though there are homeostatic mechanisms preventing zinc from achieving a level in the brain that would cause pathological results, there are cases where neurological symptoms follow zinc intoxication [1]. One case relates how a young male child induced lethargy and focal neurological reduction following 72 hours after ingesting as much as 12 grams of metallic type zinc [19]. Previous studies have shown that zinc can function as a neuromodulator [20, 21]. Other studies have demonstrated that zinc within the body could be a rapid and potent neurotoxin, as well as a gliotoxin [22, 23, 24]. Other substantial neural health issues will now be discussed.

Previous studies have shown that an exposure to zinc at a level of 300 μ M to 600 μ M, for as little as 15 minutes, can induce extensive neuronal death in tissue culture of cortical cells [25]. Zinc has been shown to be active in neuronal damage, participates in action during membrane depolarization following acute brain injury to increase its neurotoxicity [26]. This membrane depolarization causes an increase of zinc to act as a neurotoxin [27].

Other studies have described zinc as a necessary component of excito-toxic cascade following seizures, ischemia (inadequate blood supply to an organ, especially the heart muscles), and head related trauma [28, 29].

Damage to the brain regions out of broad ischemia to hippocampal CA1, thalamus, neocortex, and striatum have shown zinc accumulation among dying or dead neurons [30]. This event has also been shown to occur in the hippocampal hilar region [30]. The fact that this event described above can be prevented by intraventricular injection of zinc chelator calcium-EDTA (Edetate Calcium Disodium) supports the assertion that zinc accumulation leads to neuronal cell death [31].

Previous studies have associated zinc to a oxidative stress type induction to neuron cell damage [32]. Inclusive is a study showing zinc-induced neuron cell death occurring with increased levels of reactive oxygen species occurring within neurons [33]. Seen as a support for this scenario of zinc action on neurons, the zinc-induced cell death is decreased by introduction of anti-oxidant agents [34].

A zinc-induced apoptosis event in neurons can take place by a pathway triggering caspase activation (and apoptosis) by induction of p75^{NTR}-associated death executor and neutrophin receptor p75^{NTR} [35, 36].

The release of intracellular zinc will initiate neuronal apoptosis [37, 38], with accompanied cell swelling and destruction of intracellular organelles [39, 37]. Altogether, these studies suggest that zinc-initiated neuronal cell death encompasses both apoptotic and necrotic mechanisms (cell injury, which results in the premature death of cells) [29].

Previous studies have shown the likelihood that zinc is involved in certain neurodegenerative diseases [40]. The improper regulation of zinc homeostasis and zinc may play a substantial role for the onset and progression of Alzheimer's disease [40].

Other unfortunate cases include the fatal accidental **over** dose of zinc to a neonate following confusion of amounts of micrograms to milligrams [41]. A study conducted in Nepal showed that zinc phosphide occurred in 6.5% of all poison cases occurring in 2004 [42]. Also, acute intravenous zinc poisoning occurs from poor administration of parenteral nutrition with intravenous injection [43].

173 In addition to pathological conditions described above, symptoms from zinc deficiency such
174 as growth retardation, skin changes, poor appetite, mental lethargy, taste abnormalities,
175 slow wound healing have been noted in even moderate zinc deficiency [44]. The condition of
176 zinc deficiency is aggravated by low dietary intake, alcohol abuse, malabsorption, and
177 chronic renal disease [1, 44]. Zinc deficiency is seen to be widespread and has a destructive
178 impact on neuronal development, as well as immunity of the patient [1].
179

180 Therefore, it is seen that endogenous zinc can be substantially involved with cytotoxic
181 actions in individual cells. Studies have shown that zinc has a notably activity in cell death
182 occurring in the brain [1]. However, zinc is considered to be one of the essential minerals for
183 human health. The dual role that zinc plays in human health and clinical pathology deserves
184 further study. To understand the role zinc plays in pathological events is important, in order
185 to determine a remedial course of treatment. Therefore, the investigation will continue and
186 elucidate important facets of zinc in the human body.
187

188 **4. CONCLUSION**

189
190 Endogenous zinc is known to have important involvement within cytotoxic activity within
191 individual cells. Zinc excess is shown to induce lethargy and focal neuronal reduction. Zinc
192 deficiency has been shown to induce lethargy, neurosensory pathology, neuropsychiatric
193 disorders, and reduction of nerve conduction. Oral ingestion of toxic levels of zinc will
194 produce symptoms of dizziness and lethargy. The inhalation of zinc can bring about
195 shaking, fatigue, and fever. Although zinc acts as a neuromodulator, endogenous zinc can
196 be a potent and rapid neurotoxin. At 300 μ M levels, zinc will extensively destroy cortical
197 cells in tissue culture. Neurons exposed to zinc will initiate apoptosis. The activity of zinc in
198 the human body has significant implications for normal health. Zinc in excess or deficit will
199 cause pathological conditions which should be rapidly diagnosed by clinicians. Further study
200 of the biological activity of zinc is warranted.
201

202 **COMPETING INTERESTS**

203
204 Authors have declared that no competing interests exist.
205

206 **CONSENT**

207
208 Not applicable.
209

210 **ETHICAL APPROVAL (WHERE EVER APPLICABLE)**

211
212 Not applicable.
213

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