Journal of Advances in Medicine and Medical Research

25(10): 1-11, 2018; Article no.JAMMR.40072
ISSN: 2456-8899
(Past name: British Journal of Medicine and Medical Research, Past ISSN: 2231-0614, NLM ID: 101570965)

Aerosolized Coal Fly Ash: Risk Factor for Neurodegenerative Disease

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Authors' contributions

This work was a joint effort between the authors that is part of an ongoing collaboration aimed at providing scientific, medical, public health implications and evidence related to aerosolized coal fly ash including its use in the near-daily, near-global covert geoengineering activity. Author MW was primarily responsible for medical and public health considerations. Author JMH was primary responsible for mineralogical and geophysical considerations. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JAMMR/2018/40072
Editor(s):
(1) Jera Kruja, Neurology, University of Medicine, Tirana, Albania.
Reviewers:
(1) Normah Awang, Universiti Kebangsaan Malaysia, Malaysia.
(2) Eric S. Hall, U.S.A.
(3) Sofia Borrego Alonso, Cuba.
(4) Lourens J. C. Erasmus, University of Limpopo, South Africa.
Complete Peer review History: http://www.sciencedomain.org/review-history/23779

Review Article

Received 7th January 2018
Accepted 19th March 2018
Published 22nd March 2018

ABSTRACT

Aims: Coal fly ash (CFA), the major waste product of coal-burning utilities, is trapped and contained in Western nations, but not generally in India and China, where it is a major component of air pollution. In Western nations, the CFA trapping is inefficient, exposing downwind populations to the toxic aerosols. Similarly, CFA industry workers and those living downwind of coal ash piles may be exposed to the wind-blown toxins. Aerosolized coal fly ash, especially as used for climate manipulation, is a particularly hazardous form of air pollution. Our objective is to review the multifold components of coal fly ash, linked to neurodegenerative disease, which is rapidly increasing world-wide.
Methods: We review the interdisciplinary scientific and medical literature.

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Results: The recent finding of spherical exogenous magnetite (Fe_3O_4) nanoparticles in the brain tissue of persons with dementia suggests an origin in air pollution produced by coal fly ash. The primary components of coal fly ash, iron oxides and aluminosilicates, are all found in the abnormal proteins that characterize Alzheimer's dementia. The presence of these substances in brain tissue leads to oxidative stress and chronic inflammation. Energy absorbed by magnetite from external electromagnetic fields may contribute to this neuropathology.
Conclusions: Considering the well-known and manifold toxicities of CFA, the public should be made aware of the potential risks for neurodegenerative disease posed by aerosolized CFA, including its use in climate alteration activities. We have set forth the basis for understanding how this kind of pollution may damage cognitive abilities. It is a form of pollution that should be halted altogether.

Keywords: Aerosols; coal fly ash; climate intervention; Alzheimer's; Parkinson's; dementia; brain disease.

1. INTRODUCTION

Burning coal accounts for one-third of global energy utilization and 40% of the electricity generated throughout the world [1]. Unlike burning natural gas, burning coal produces solid ash in amounts of approximately 10% of the initial coal weight. The heavy coal ash settles beneath the burner, while the light ash, called coal fly ash (CFA), condenses and accumulates in the vapors above the burner, and exits with the exhaust gases. Being a concentrate of the toxins originally present in the coal, in Western nations, CFA is electrostatically trapped and sequestered. India and China, however, frequently do not trap CFA, and it is a major contributor to air pollution in those nations [2].

Even in Western nations, the public is exposed, in some locations, to aerosolized CFA pollution downwind of coal-burning utilities with inefficient trapping [3,4], downwind of CFA coal ash piles [5], and as workers in the coal fly ash industry [6]. On a larger scale, forensic evidence is consistent with coal fly ash as the primary material utilized in undisclosed and ongoing tropospheric aerosol climate manipulation operations in North America and Europe [7,8].

Air pollution is one of the great killers of our age. It is increasing at an alarming rate and is currently the fourth leading cause of death world-wide [9]. Exposure to air pollution is known to be associated with respiratory, cardiovascular, and stroke-related morbidity and mortality [10,11].

In this Review, we disclose potential risk factors and toxicological evidence of neurological degenerative diseases resulting from aerosolized CFA.

The prevalence of dementia is higher in developed countries than in developing ones, but it is rapidly increasing throughout the world [12]. It has been projected that the number of people affected by dementia will double between 2020 and 2040 [13]. Data suggest that air pollution is a significant risk factor for neurodegenerative disease including Alzheimer's dementia (AD) and Parkinson's disease (PD). Long-term exposure to air pollution is associated with neuroinflammation, altered immune response, disruption of the blood-brain barrier, particulate deposition, and accumulation of amyloid plaques in the brain [14].

A recent study documents significant adverse health effects from $PM_{2.5}$ at concentrations below national standards [15]. Ultrafine particles (UFP), those particles less than 0.1 um in diameter, contribute negligibly to $PM_{2.5}$, but dominate the particle number count (PNC). There is no regulation or effective monitoring of these ultrafine/nanoparticles [16]. UFP's are among the most toxic particles based on their greater number, larger content of redox active compounds, greater surface-to-mass ratio, bioavailability of chemically active agents, and their ability to penetrate cell walls [17].

Over recent decades, the central nervous system (CNS) has been a suspected target of the harmful effects of air pollution. In one of the first indications, indoor coal fumes were found to be an independent risk factor for stroke (cerebrovascular accident/CVA) [18]. Somewhat later, air pollution was found to be an important risk factor for ischemic stroke [19]. The first study to show that air pollution might be related to neurodegenerative disease used dogs from a highly polluted urban area. Brain damage in the exposed dogs (compared to controls) included

disruption of the blood-brain barrier, degenerating cortical neurons, non-neuritic plaques, and neurofibrillary tangles. Tissue damage was greatest in the olfactory mucosa, olfactory bulb, and frontal cortex, implicating the nasal pathway as portal of entry [20]. It was later shown in rats that inhaled ultrafine particles can translocate to the brain [21].

In recent years, emerging evidence from epidemiological, observational, clinical, and experimental studies strongly suggest AD, PD, certain other neurodegenerative diseases, and stroke in humans, are associated with ambient air pollution [22]. Children residing in a highly polluted urban environment were found to have cognitive deficits, and the majority of them demonstrated brain abnormalities on MRI [23]. A link between exposure to air pollution and AD was found by Jung and colleagues in a Taiwanese cohort of over 95,000 people age 65 or older [24]. Long-term exposure to $PM_{2.5-10}$ levels typically experienced in the U.S. was found to be associated with cognitive decline in elderly women [25].

2. METHODS

There is much information in the scientific literature pertaining to the subject of this review, however, it is spread among different journals across several disciplines. We review relevant medical and scientific literature to collate diverse information and thus draw inferences on the adverse health risks for neurological degenerative diseases due to atmospheric aerosol climate alteration based upon the compositional nature of CFA and the commonalities disclosed by air pollution investigations. Principal search engines used are the Florida State Internet and Google Scholar.

3. RESULTS AND DISCUSSION

The primary mineral components of CFA are silicates, aluminum-containing compounds, and an iron-bearing component that includes magnetite (Fe_3O_4) [26]. Notably, all of these component-elements are found in AD plaque core material including iron, aluminum and silicon [27]. Iron and aluminum are both implicated in the pathogenesis of neurodegenerative diseases. In both AD and PD, iron accumulates in the brain, indicating a loss of iron homeostasis and resultant iron-induced oxidative stress [28]. The recent finding of exogenous magnetite nanoparticles in brain tissue of persons with dementia lends strong support to the relationship between air pollution, iron compounds, and neurodegeneration [29]. As we discuss, the components of CFA, as utilized in atmospheric climate manipulation, pose similar, if not more severe, potential risk-factors for neurodegenerative diseases.

The relative amount of ultrafine particulate matter and nanoparticles is higher in CFA than any other combustion-derived material. The average size range of CFA nanoparticles fall within the range of $PM_{0.1}$ [30]. Ultrafine particles in CFA often escape filtering devices like electrostatic precipitators [4]. Coal fly ash that is not trapped by pollution control devices contributes to the fine particle ($PM_{2.5}$) component of particulate matter. These particles stay in the atmosphere longer and can be transported greater distances [31]. Duration time and transport distances are much greater for aerosolized CFA used for climate manipulation. Aluminosilicate glass is a dominant material in fly ash particles. Atmospheric weathering of this aluminosilicate phase can mobilize iron (Fe), which is present in the inner core or surface of fly ash spheres [32]. Iron ions are among the most hazardous components of PM, as they produce the most reactive oxygen species [33].

A large body of evidence suggests that neurodegenerative disorders are partially mediated by oxidative stress. The brain is highly susceptible to oxidative stress injury because of its high metabolic activity, its low antioxidant activity, its high cellular content of lipids and proteins, and its large amount of redox active metals such as iron, copper, molybdenum, and zinc, all components of CFA [22]. Biometals such as these are essential for neuronal function, but their deficiency, excess, or dysregulation can lead to neurogenerative disease. Homeostasis of transition metals in the brain is disturbed in AD, with extracellular pooling of zinc and copper in amyloid plaques, and intraneuronal accumulation of iron. Amyloid and tau protein pathology arise in the setting of high metal flux, and as these proteins are involved in both transition metal import and export, they may contribute to AD by developing defective metal transport roles [34]. Dysfunctional transition metal metabolism, transport, accumulation, and storage can result from either endogenous disorders or exogenous insults [35]. The recent findings of particulate matter, including magnetite pollution nanoparticles in the brains of persons with AD, generally and strongly implicates air

pollution as the essential, primary external environmental causative factor leading to neurodegeneration [29].

Maher et al. [29] distinguished exogenous magnetite nanoparticles in brain tissue of persons with dementia by their spherical particle-shape, which is different from biogenic magnetite. Coal fly ash is principally composed of spherical particles, including magnetite spheres, which condensed from and agglomerated in, the hot gas above the burner. The spherical shape results from the surface tension of the melt (Fig. 1).

Natural rocks and minerals tend to form slowly or form from matter which formed slowly, approaching thermochemical equilibrium. Consequently, some degree of stability generally may be expected, except over long periods of time or in corrosive environments. By contrast, CFA condensed and/or accumulated and cooled rapidly under circumstances quite unlike natural terrestrial environments. Consequently, water [36] as well as body fluids [37,38] are capable of extracting from CFA a large number of elements, many toxic and/or carcinogenic, and in the process produces chemically reactive surfaces.

The morphology of CFA is diverse, but most of the particles are microspheres, porous microspheres, plerospheres containing sub-microspheres or mineral fragments, and magnetic ferrospheres [39]. The ultrafine particles (0.1-1 um), and nanometer-sized particles (< 100 nm) in CFA, characterized by

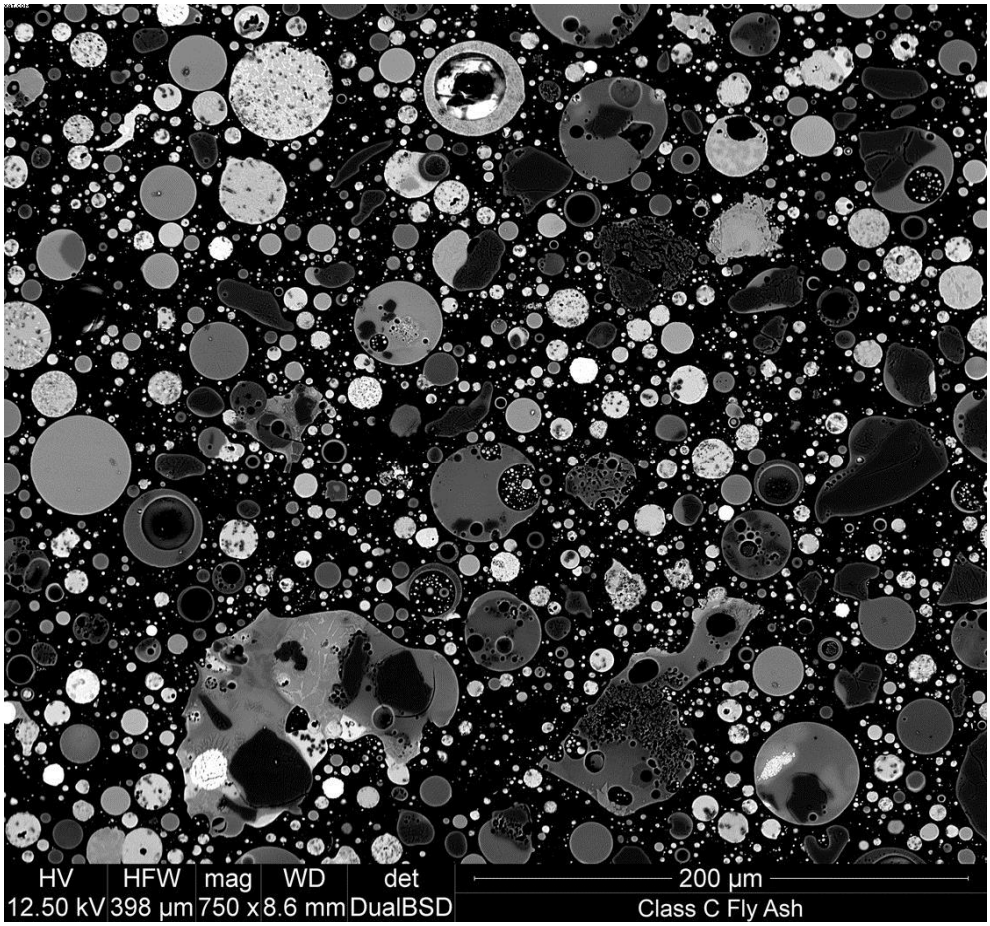

Fig. 1. Polished cross section of coal fly ash (ASTM C 618 Class C) embedded in epoxy. The image was obtained from back-scattered electrons which show differences in atomic density represented by variation in gray scale. The overwhelming spherical morphologies are the consequence of the surface tensions of the melts during condensation from and agglomeration in the hot gas above the coal-burner (Courtesy of Wabeggs: CC BY-SA 3.0)

energy-filtered transmission electron microscopy, are often spherules embedded in a silica matrix with metallic elements like aluminum, iron, and titanium [31].

Coal fly ash contains significant amounts of magnetic iron oxides, especially magnetite (Fe_3O_4). Magnetic particles tend to be spheroidal, especially with decreasing particle size [40]. High-resolution transmission electron microscopy studies of nanometric-sized crystalline phases in CFA reveal iron-rich oxides, Fe-sulfate, and heterogeneous Fe-aluminum silicate particles with abundance peaks at 10 and 100 nm [41] (Table 1). This particle size is consistent with biogenic magnetite in human brain tissue (most 10-70 nm) [42] and exogenous pollution magnetite nanoparticles in human brain tissue (10-150 nm) [29]. Iron speciation by Mossbauer spectroscopy indicates that ferric iron in an aluminosilicate phase is a source of the bioavailable iron in CFA, and that this iron is associated with combustion particles and not crustal dust. Such bioavailable iron has been shown to produce reactive oxygen species in cell culture experiments [43].

The primary elements in coal fly ash, i.e., iron, aluminum, and silicon, have all been found in core plaque material in AD. Aluminum and silicon were found co-localized in the central region of senile plaque cores in the 1980's [45], with these findings confirmed by more recent studies [27]. The presence of aluminum and silicon as aluminosilicates was documented using solid-state ^{27}Al nuclear magnetic resonance spectroscopy. Al and Si have also been reported in the neurofibrillary tangle-bearing neurons which characterize AD [46]. The presence of aluminosilicates (which have no known biologic function) in these abnormal sites suggests they may play a role in neuropathology. The potential pathogenic role of microglial cells in the neurodegenerative process is suggested by the finding that murine microglial cells, exposed in vitro to aluminosilicate particles, stimulate tissue-injurious free radical reactive oxygen metabolites [47]. This particle-induced activation of glial macrophage cells promotes chronic inflammation and deposition of the abnormal protein material that characterizes AD [48]. The presence of Al^{3+} in plaques also potentiates the redox cycle in favor of the more toxic ferrous (Fe^{2+}) iron at these sites [49].

Iron is essential for brain function, but its imbalance or excess is a potent source of reactive oxygen species. Iron accumulates with aging and excessive iron occurs in many neurodegenerative diseases including AD, PD, and Huntington's disease, amyotrophic lateral sclerosis, and several genetic neurological diseases under the category NBIA: Neurodegeneration with Brain Iron Accumulation. Iron has two valence states, ferric iron (Fe^{3+}), and ferrous iron (Fe^{2+}) which in living systems allows its use in uptake, mobilization, storage, transport, etc. However, the ability of iron to exchange single electrons with multiple substrates can lead to generation of reactive oxygen species (ROS). An excess of ferrous iron can be toxic, e.g., by reacting with hydrogen peroxide (H_2O_2) via the Fenton reaction, or with peroxynitrates, catalyzing oxidant-mediated damage. The result of abnormal iron chemistry can lead to oxidative stress, lipid peroxidation, and DNA damage that ultimately causes death of irreplaceable neurons by apoptosis (programmed cell death) [27,50]. Under normal conditions in the body, a highly complex and fine-tuned regulatory system controls Fe homeostasis on both an intra and extracellular basis, severely limiting the amount of free, available ionic iron. There is evidence that a build-up of iron and

Table 1. Classifications of mineral-chemical compositions of ferrospheres in CFA, from measurements on 60 spheres [44], based upon the major elements iron (Fe), aluminum (Al), and silicon (Si), which are observed in neurologically degenerate tissue samples. Cations are normalized to 100 % by weight

Ferrosphere	Fe content	(Al+Si) content
Classification	Wt. %	Wt. %
Ferrooxides	Fe ≥ 75	(Al+Si) ≤ 25
Aluminosilicate-containing Ferrooxides	50 ≥ Fe < 75	25 < (Al+Si) ≤ 50
High-ferriferous Aluminosilicates	25 ≤ Fe > 50	50 > (Al+Si) ≤ 75
Ferroaluminosilicates	Fe < 25	(Al+Si) > 75

oxidative stress precedes the development of amyloid plaques and neurofibrillary tangles that characterize AD [28].

Microglia are the resident immune surveillance cells in the brain, and they are activated in neurodegenerative diseases. Microglia are activated in response to disease proteins, cytokines, neuron death, and environmental toxins, including components of air pollution. Microglia were first shown to recognize and respond to PM in an in vitro study of diesel exhaust particles [51,52]. While most of the microglial activity is beneficial, an excess of activated microglia can become a source of chronic inflammation and oxidative stress. It has been found that activated iron-containing microglia are numerous in the hippocampus (a key portion of the brain relating to memory function) of persons with AD compared to controls [53]. Iron-containing monocytes from peripheral blood can migrate across the blood-brain-barrier in neurodegenerative disease, where they transform into brain macrophages. These macrophages participate in the phagocytosis of dead and dying cells, and eventually die themselves, leading to the release of their iron into the central nervous system. This iron could transform from ferric iron present in the storage protein ferritin to the more available but more labile and toxic ferrous iron [54].

Magnetite (Fe_3O_4) is a ferrimagnetic iron oxide crystal with alternating lattices of Fe (II) and Fe (III) which are antiferromagnetically coupled. This alternation of lattices and their corresponding differences in the number of unpaired electron spins give magnetite its strong magnetization [55]. Magnetite is formed biochemically by many living organisms including man. Biogenic magnetite was first discovered in human brain tissues in 1992. Biogenic magnetite nanoparticles occur as angular, crystalline particles, most in the 10-70 nm size range. Biogenic magnetite particles are often found in “clumps” or chains, usually within a “closed system” of lipid membranes called magnetosomes [42]. Since the discovery of biogenic magnetite, particles of this material have been extracted, imaged, and characterized by transmission electron microscopy and SQUID magnetometry. Recently magnetite pollution nanoparticles were found in abundance in the brain tissue of persons with advanced dementia [29]. These particles match the high-temperature magnetite nanospheres of CFA, which formed by condensation from hot combustion-gas. The pollution particles have diameters between 10 and 150 nanometers and can enter the brain directly through the olfactory nerve and especially through the injured olfactory apparatus, including the olfactory bulb [29].

Neurofibrillary tangles and amyloid [senile] plaques are major sites for catalytic redox reactivity of transition metals, including iron. This lesion-associated iron is distinct from iron sequestered in ferritin and provides evidence of reactive ferrous (Fe^{+2}) in AD tissue [55,56]. β-amyloid (BA) is capable of accumulation and co-aggregation of iron within plaque structures, resulting in the chemical reduction of redox-inactive ferric to redox-active ferrous iron. The presence of aluminum increases this reductive activity [57]. Both iron and aluminum can induce aggregation of hyperphosphorylated t (PHFt), the major constituent of neurofibrillary tangles [58]. The excess iron found in neurodegenerative disease may be in the form of magnetite [59]. Using an integrative set of advanced transmission electron microscopy techniques, it has been shown that Fe in amyloid plaque cores is present as iron oxide nanoparticles. These highly organized nanostructures are bound into fibrillar BA and demonstrate superparamagnetic properties [60]. In an in-vitro model, the combination of magnetite and β-amyloid disrupts the functional organization of cultured neuronal networks [61]. Malfunction of the light polypeptide of ferritins leads to the formation of superparamagnetic magnetite. The presence of this magnetite may reduce the bioavailability of iron, and potentiate free radical production by Fenton reaction and/or triplet state stabilization [62].

Magnetite is the only ferromagnetic compound in the body, and it reacts over one million times more strongly to external electromagnetic fields than any other biological substance [42]. Electromagnetic frequencies absorbed by magnetite are transduced into acoustic vibrations at the microwave frequency within the crystal lattice via the magneto-acoustic effect. This energy is dissipated into cellular structures close to the magnetite particles. Magnetite best absorbs microwave frequencies in the 0.5 - 10 Gigahertz range, but it can also be affected by radio frequencies and extremely low frequencies (ELF). We are surrounded by sources of electromagnetic radiation in that absorption frequency range including Bluetooth, GPS, smart meters, microwave ovens, mobile phones,

wireless LAN, and ZigBee – to name a few. Mechanically-sensitive ion channels can open or close from the movement of magnetite in response to external electromagnetic fields [63]. This transient opening of membrane pores allows calcium and other ions to enter cells. There is evidence that voltage-gated calcium channels (VGCC) may provide an alternative route for iron to enter neurons and produce oxidative toxicity [64].

Electromagnetic Fields (EMF's) are associated with oxidative stress in the human brain and contribute to neurodegeneration [65,66]. Microwave frequency EMF's have also been shown to produce neuropsychiatric effects [67]. Microwave radiation is damaging to brain cells not by thermal effects, but rather by vibration effects on cellular structures and processes. The magnetite pollution nanoparticles in the brains of persons with advanced dementia greatly outnumber the biogenic magnetite particles [29]. Exogenous pollution particles may also absorb and transduce a wide variety of man-made electromagnetic frequencies [63].

4. CONCLUSION

Virtually everyone in the world is now exposed to air pollution, the leading environmental cause of disease and death. Air pollution is linked to neurodegenerative disease and dementia, which is reaching pandemic proportions. The recent finding of exogenous magnetite nanoparticles in brain tissue is like a "smoking gun," indicating a strongly supported relationship between pollution formed by combustion and neurodegenerative disease. Among several sources of exogenous neurologically damaging magnetite pollution, we have shown that the size and morphology of these particles is most consistent with an origin in coal fly ash. The principal components of coal fly ash, i.e., aluminosilicates and magnetite, are all found in in the abnormal protein material that characterizes Alzheimer's Dementia. Magnetite is extremely sensitive to external electromagnetic fields and this fact hints at a synergistic role of electromagnetic fields in producing neurodegeneration. Additional research is urgently needed to confirm and further investigate these findings.

There is published evidence consistent with coal fly ash being the main component utilized in atmospheric aerosol climate manipulation. This activity, now conducted on a near-daily, near-global basis represents an unacknowledged, involuntary, and extremely toxic form of air pollution with potential global impacts. There is no effective regulation or monitoring of the principal elements (e.g., Al, Si, and Fe) in aerosolized coal fly ash. The ultrafine and nanoparticles present in coal fly ash often go unfiltered and undetected. We have set forth the basis for understanding how this kind of pollution may damage the cognitive abilities of human populations. It is a form of pollution that should be halted altogether.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable as no human or animal subjects were involved.

ACKNOWLEDGEMENT

The authors thank Environmental Voices and its donors for generously providing funds for publication fees.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Available:http://wwwieaorg/topics/coal/ International Energy Agency.
   (Accessed March 10, 2018.
2. Carlson CL, Adriano DC. Environmental Impacts of Coal Combustion Residues. Journal of Environmental Quality. 1993; 22(2).
3. Mohr M, Ylätalo S, Klippel N, Kauppinen E, Riccius O, Burtscher H. Submicron fly ash penetration through electrostatic precipitators at two coal power plants. Aerosol Science and Technology. 1996; 24(3):191-204.
4. Zhuang Y, Kim YJ, Lee TG, Biswas P. Experimental and theoretical studies of ultra-fine particle behavior in electrostatic precipitators. Journal of Electrostatics. 2000;48(3):245-260.

5. Baxter M. Environmental radioactivity: A perspective on industrial contributions. IAEA Bulletin. 1993;35(2):33-38.
6. Stierum R, Hageman G, Welle I, Albering H, Schreurs J, Kleinjans J. Evaluation of exposure reducing measures on parameters of genetic risk in a population occupationally exposed to coal fly ash. Mutation Research/Genetic Toxicology. 1993;319(4):245-255.
7. Herndon JM, Whiteside M. Further evidence of coal fly ash utilization in tropospheric geoengineering: Implications on human and environmental health. J Geog Environ Earth Sci Intn. 2017;9(1):1-8.
8. Herndon JM, Whiteside M. Contamination of the biosphere with mercury: Another potential consequence of on-going climate manipulation using aerosolized coal fly ash J Geog Environ Earth Sci Intn. 2017;13(1):1-11.
9. World Health Organization. Ambient air pollution: a global assessment of exposure and burden of disease. Ambient air pollution: A global assessment of exposure and burden of disease; 2016.
10. Brunekreef B, Holgate ST. Air pollution and health. The Lancet. 2002;360(9341):1233-1242.
11. Pope A, Burnett R, Thun M, Thurston G. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA. 2002;287(9):1132-1141.
12. Rizzi L, Rosset I, Roriz-Cruz M. Global epidemiology of dementia: Alzheimer's and vascular types. BioMed Research International. 2014;2014.
13. Ferri CP, Prince M, Brayne C, Brodaty H, Fratiglioni L, Ganguli M, et al. Global prevalence of dementia: A Delphi consensus study. The lancet. 2006;366(9503):2112-2117.
14. Calderón-Garcidueñas L, Solt AC, Henríquez-Roldán C, Torres-Jardón R, Nuse B, Herritt L, et al. Long-term air pollution exposure is associated with neuroinflammation, an altered innate immune response, disruption of the blood-brain barrier, ultrafine particulate deposition, and accumulation of amyloid β-42 and α-synuclein in children and young adults. Toxicologic Pathology. 2008; 36(2):289-310.
15. Di Q, Wang Y, Zanobetti A, Wang Y, Koutrakis P, Choirat C, et al. Air Pollution and Mortality in the Medicare Population. New England Journal of Medicine. 2017;376(26):2513-2522.
16. Koehler KA, Peters T. New methods for personal exposure monitoring for airborne particles. Current Environmental Health Reports. 2015;2(4):399.
17. Araujo JA, Nel AE. Particulate matter and atherosclerosis: Role of particle size, composition and oxidative stress. Particle and Fibre Toxicology. 2009;6(1):24.
18. Zhang Z-F, Yu S-Z, Zhou G-D. Indoor air pollution of coal fumes as a risk factor of stroke, Shanghai. American Journal of Public Health. 1988;78(8):975-977.
19. Hong YC, Lee JT, Kim H, Kwon HJ. Air pollution: A new risk factor in ischemic stroke mortality. Stroke. 2002;33:2165-2169.
20. Calderón-Garcidueñas L, Azzarelli B, Acuna H, Garcia R, Gambling TM, Osnaya N, et al. Air pollution and brain damage. Toxicologic Pathology. 2002;30(3):373-389.
21. Oberdörster G, Sharp Z, Atudorei V, Elder A, Gelein R, Kreyling W, et al. Translocation of inhaled ultrafine particles to the brain. Inhalation Toxicology. 2004;16(6-7):437-445.
22. Genc S, Zadeoglulari Z, Fuss SH, Genc K. The adverse effects of air pollution on the nervous system. Journal of Toxicology. 2012;2012.
23. Calderón-Garcidueñas L, Mora-Tiscareño A, Ontiveros E, Gómez-Garza G, Barragán-Mejía G, Broadway J, et al. Air pollution, cognitive deficits and brain abnormalities: A pilot study with children and dogs. Brain and cognition. 2008;68(2):117-127.
24. Jung CR, Lin YT, Hwang BF. Ozone, particulate matter, and newly diagnosed Alzheimer's disease: A population-based cohort study in Taiwan. Journal of Alzheimer's Disease. 2015;44(2):573-584.
25. Weuve J, Puett RC, Schwartz J, Yanosky JD, Laden F, Grodstein F. Exposure to particulate air pollution and cognitive decline in older women. Archives of internal medicine. 2012;172(3):219-227.
26. Fisher GL. Biomedically relevant chemical and physical properties of coal combustion

products. Environ Health Persp. 1983; 47:189-199.

27. Collingwood JF, Chong RK, Kasama T, Cervera-Gontard L, Dunin-Borkowski RE, Perry G, et al. Three-dimensional tomographic imaging and characterization of iron compounds within Alzheimer's plaque core material. Journal of Alzheimer's Disease. 2008;14(2):235-245.
28. Castellani RJ, Moreira PI, Liu G, Dobson J, Perry G, Smith MA, et al. Iron: The Redox-active center of oxidative stress in Alzheimer disease. Neurochemical research. 2007;32(10):1640-1645.
29. Maher BA, Ahmed IAM, Karloukovski V, MacLauren DA, Foulds PG, al. e. Magnetite pollution nanoparticles in the human brain. Proc Nat Acad Sci. 2016;113(39):10797-10801.
30. Sambandam B, Palanisami E, Abbugounder R, Prakhya B, Thiyagarajan D. Characterizations of coal fly ash nanoparticles and induced in vitro toxicity in cell lines. Journal of Nanoparticle Research. 2014;16(2):2217.
31. Chen Y, Shah N, Huggins F, Huffman G, Dozier A. Characterization of ultrafine coal fly ash particles by energy filtered TEM. Journal of Microscopy. 2005;217(3):225-234.
32. Chen H, Grassian VH, Saraf LV, Laskin A. Chemical imaging analysis of environmental particles using the focused ion beam/scanning electron microscopy technique: microanalysis insights into atmospheric chemistry of fly ash. Analyst. 2013;138(2):451-460.
33. Lakey PS, Berkemeier T, Tong H, Arangio AM, Lucas K, Pöschl U, et al. Chemical exposure-response relationship between air pollutants and reactive oxygen species in the human respiratory tract. Scientific Reports. 2016;6:32916.
34. Bush AI. The metal theory of Alzheimer's disease. Journal of Alzheimer's Disease. 2013;33(s1):S277-S281.
35. Zheng W, Monnot AD. Regulation of brain iron and copper homeostasis by brain barrier systems: Implication in neurodegenerative diseases. Pharmacology & Therapeutics. 2012; 133(2):177-188.
36. Moreno N, Querol X, Andrés JM, Stanton K, Towler M, Nugteren H, et al. Physico-chemical characteristics of European pulverized coal combustion fly ashes. Fuel. 2005;84:1351-1363.
37. Gilmour MI, O'Connor S, Dick CAJ, Miller CA, Linak WP. Differential pulmonary inflamation and in vitro cytotoxicity of size-fractionated fly ash particles from pulverized coal combustion. Air & Water Manage Assoc. 2004;54:286-295.
38. Twining J, McGlinn P, Lol E, Smith K, Giere R. Risk ranking of bioaccessible metals from fly ash dissolved in simulated lung and gut fluids. Environ Sci Technol. 2005;39(19):7749-7756.
39. Liu H, Sun Q, Wang B, Wang P, Zou J. Morphology and Composition of Microspheres in Fly Ash from the Luohuang Power Plant, Chongqing, Southwestern China. Minerals. 2016;6(2):30.
40. Bhattacharjee A, Mandal H, Roy M, Kusz J, Hofmeister W. Physical characteristics of fly ashes from three thermal power plants in West Bengal, India: A comparative study. International Journal of Chem Tech Research. 2013;5(2):836-843.
41. Silva L, Moreno T, Querol X. An introductory TEM study of Fe-nanominerals within coal fly ash. Science of the Total Environment. 2009; 407(17):4972-4974.
42. Kirschvink JL, Kobayashi-Kirschvink A, Woodford BJ. Magnetite biomineralization in the human brain. Proceedings of the National Academy of Sciences. 1992; 89(16):7683-7687.
43. Veranth JM, Smith KR, Huggins F, Hu AA, Lighty JS, Aust AE. Mössbauer spectroscopy indicates that iron in an aluminosilicate glass phase is the source of the bioavailable iron from coal fly ash. Chemical Research in Toxicology. 2000;13(3):161-164.
44. Zhao Y, Zhang J, Sun J, Bai X, Zheng C. Mineralogy, chemical composition, and microstructure of ferrospheres in fly ashes from coal combustion. Energy & Fuels. 2006;20(4):1490-1497.
45. Edwardson J, Klinowski J, Oakley A, Perry R, Candy J. Aluminosilicates and the ageing brain: Implications for the pathogenesis of Alzheimer's disease. Silicon Biochemistry. 1986:160-179.
46. Candy J, Klinowski J, Perry R, Perry E, Fairbairn A, Oakley A, et al. Aluminosilicates and senile plaque

formation in Alzheimer's disease. The lancet. 1986;327(8477):354-356.

47. Evans PH, Yano E, Klinowski J, Peterhans E. Oxidative damage in Alzheimer's dementia, and the potential etiopathogenic role of aluminosilicates, microglia and micronutrient interactions. Free Radicals and Aging: Springer. 1992;178-189.
48. Evans P, Harrington C. Aluminosilicate Particulate and Beta-Amyloid in Vitro Interactions: A Model of Alzheimer Plaque Formation. Annals of the New York Academy of Sciences. 1998;854(1):492.
49. Khan A, Dobson JP, Exley C. Redox cycling of iron by Aβ 42. Free Radical Biology and Medicine. 2006;40(4):557-569.
50. Gozzelino R, Arosio P. Iron homeostasis in health and disease. International Journal of Molecular Sciences. 2016;17(1):130.
51. Block M, Wu X, Pei Z, Li G, Wang T, Qin L, et al. Nanometer size diesel exhaust particles are selectively toxic to dopaminergic neurons: The role of microglia, phagocytosis, and NADPH oxidase. The FASEB Journal. 2004;18(13):1618-1620.
52. Block ML, Calderón-Garcidueñas L. Air pollution: mechanisms of neuroinflammation and CNS disease. Trends in Neurosciences. 2009;32(9):506-516.
53. Zeineh MM, Chen Y, Kitzler HH, Hammond R, Vogel H, Rutt BK. Activated iron-containing microglia in the human hippocampus identified by magnetic resonance imaging in Alzheimer disease. Neurobiology of Aging. 2015;36(9):2483-2500.
54. Andersen HH, Johnsen KB, Moos T. Iron deposits in the chronically inflamed central nervous system and contributes to neurodegeneration. Cellular and molecular life sciences. 2014;71(9):1607-1622.
55. Dobson J. Nanoscale biogenic iron oxides and neurodegenerative disease. FEBS letters. 2001;496(1):1-5.
56. Sayre LM, Perry G, Harris PL, Liu Y, Schubert KA, Smith MA. In situ oxidative catalysis by neurofibrillary tangles and senile plaques in Alzheimer's disease. Journal of Neurochemistry. 2000; 74(1):270-279.
57. Everett J, Céspedes E, Shelford LR, Exley C, Collingwood JF, Dobson J, et al. Ferrous iron formation following the co-aggregation of ferric iron and the Alzheimer's disease peptide β-amyloid (1–42). Journal of The Royal Society Interface. 2014;11(95).
58. Yamamoto A, Shin RW, Hasegawa K, Naiki H, Sato H, Yoshimasu F, et al. Iron (III) induces aggregation of hyperphosphorylated τ and its reduction to iron (II) reverses the aggregation: implications in the formation of neurofibrillary tangles of Alzheimer's disease. Journal of Neurochemistry. 2002;82(5):1137-1147.
59. Hautot D, Pankhurst Q, Khan N, Dobson J. Preliminary evaluation of nanoscale biogenic magnetite in Alzheimer's disease brain tissue. Proceedings of the Royal Society of London B: Biological Sciences. 2003;270(Suppl 1):S62-S64.
60. Plascencia-Villa G, Ponce A, Collingwood JF, Arellano-Jiménez MJ, Zhu X, Rogers JT, et al. High-resolution analytical imaging and electron holography of magnetite particles in amyloid cores of Alzheimer's disease. Scientific Reports. 2016;6:24873.
61. Teller S, Tahirbegi IB, Mir M, Samitier J, Soriano J. Magnetite-Amyloid-β deteriorates activity and functional organization in an in vitro model for Alzheimer's disease. Scientific Reports. 2015;5:17261.
62. Hautot D, Pankhurst QA, Morris CM, Curtis A, Burn J, Dobson J. Preliminary observation of elevated levels of nanocrystalline iron oxide in the basal ganglia of neuroferritinopathy patients. Biochimica et Biophysica Acta (BBA)-Molecular Basis of Disease. 2007; 1772(1):21-25.
63. Kirschvink JL. Microwave absorption by magnetite: A possible mechanism for coupling non-thermal levels of radiation to biological systems. Bioelectromag. 1996;17:187-194.
64. Gaasch JA, Geldenhuys WJ, Lockman PR, Allen DD, Van der Schyf CJ. Voltage-gated calcium channels provide an alternate route for iron uptake in neuronal cell cultures. Neurochemical Research. 2007; 32(10):1686-1693.
65. Consales C, Merla C, Marino C, Benassi B. Electromagnetic fields, oxidative stress, and neurodegeneration. International Journal of Cell Biology. 2012;2012.

66. Reale M, Kamal MA, Patruno A, Costantini E, D'Angelo C, Pesce M, et al. Neuronal cellular responses to extremely low frequency electromagnetic field exposure: Implications regarding oxidative stress and neurodegeneration. PLoS ONE. 2014; 9(8):e104973.

67. Pall ML. Microwave frequency electromagnetic fields (EMFs) produce widespread neuropsychiatric effects including depression. Journal of Chemical Neuroanatomy. 2016;75:43-51.

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