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Article

# Metallic particulates in pulmonary tissue

# Partículas metálicas en tejido pulmonar

Peña-García, Laura Elizabeth [a]*

[a] Universidad de Guadalajara • U-4752-2018 • 0000-0002-9008-1339 • 311129

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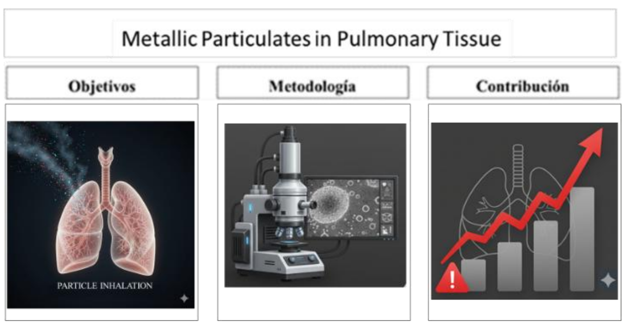
* ✉ [laura.pgarcia@academicos.udg.mx]

**Abstract**

This paper examines the toxicological consequences of metal particles (PM 2.5) deposition in lung tissue. Originating from sources such as vehicular traffic (brake/tire abrasion and emissions), these nanoparticles pose a significant health risk, particularly in high-traffic areas. Chronic exposure increases the likelihood of developing lung cancer and other respiratory and inflammatory diseases. The central mechanism of toxicity involves the induction of oxidative stress and the generation of cellular inflammation, leading to DNA damage and the activation of pro-cancer pathways, even in non-smokers. Epidemiological studies confirm an elevated risk for residents living within 500 meters of high-volume roadways.




**Metallic Particulates, pulmonary tissue, $PM_{2.5}$**

**Resumen**

Este documento examina las consecuencias toxicológicas de la deposición de partículas metálicas ($PM_{2.5}$) en tejido pulmonar. Provenientes de fuentes como el tráfico vehicular (abrasión de frenos, neumáticos y emisiones), estas nanopartículas representan un riesgo significativo para la salud, especialmente en zonas de alto flujo. La exposición crónica aumenta la probabilidad de desarrollar cáncer de pulmón y otras enfermedades respiratorias e inflamatorias. El mecanismo central de toxicidad es la inducción de estrés oxidativo y la generación de inflamación celular, lo que conduce al daño del ADN y a la activación de vías pro-cancerígenas, incluso en personas no fumadoras. Estudios epidemiológicos confirman un riesgo elevado para residentes a menos de 500 metros de carreteras con alto volumen de tráfico.


**Partículas metálicas, tejido pulmonar, $PM_{2.5}$**

**Area**: Promotion of frontier research and basic science in all fields of knowledge

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## Introduction

Measuring exposure to numerous pollutants is complex because adequate health information and surveillance systems are not always available to assess the magnitude and severity of the risks. Some substances below certain levels are not dangerous, but other agents such as allergens, ionising radiation, air pollutants and carcinogenic chemicals can pose a risk at levels higher than those observed (Vargas, 2005).

According to the World Health Organisation (WHO), exposure to air pollution is responsible for millions of premature deaths each year. The most recent figures, from associated reports by the WHO and the Health Effects Institute (HEI), estimate 8.1 million deaths annually in 2021, making air pollution the second leading risk factor for death worldwide (WHO, 2021; UN News, 2024). The main causes of death are non-communicable diseases (NCDs), such as ischaemic heart disease, stroke, chronic obstructive pulmonary disease (COPD) and lung cancer. The WHO also estimates that air pollution should be considered an ‘invisible pandemic’ due to its widespread impact on public health.

The rapid development of nanotechnology has driven the growing use of metallic nanoparticles (MNPs) in a wide range of industrial sectors and consumer products. This advance has led to a significant increase in human and environmental exposure, which is a public health priority.

Metallic particles in lung tissue are a clear example of how environmental pollution directly affects human health.

There are different routes of entry into the human body, one of which is through the inhalation of PM. Due to their small diameters, this type of material can include metal nanoparticles, which are able to evade the upper filtration mechanisms and penetrate deep into the pulmonary alveoli.

The respiratory system is the main route of entry for MP due to inhalation. Coarse particles that are transported by air (size $\leq$ 10 μm; PM 10) are deposited in the upper respiratory system. The material can be as fine as aerosols and can be transported by the bloodstream.

The presence of metal particles in human lung tissue is intrinsically linked to exposure to PM, especially fine ($PM_{2.5}$) and ultrafine ($PM_{0.1}$) particles present in air pollution (vehicular traffic, industrial emissions, combustion, etc.) or in occupational environments (mining, welding, etc. Recent research confirms that the most toxic components of $PM_{2.5}$ include metals and metalloids such as arsenic, lead, cadmium, chromium, and mercury. These are deposited in the lung, acting as a reservoir of acute and chronic exposure. People living in large cities also accumulate PM in their lungs throughout their lives due to the high levels of air pollution commonly found in urban environments (Ellwanger *et al*., 2025). The tiny size of PM (<100 nm) is one of their defining characteristics, as it facilitates their penetration through cell membranes and other biological barriers. Several studies have shown that smaller particle sizes correlate with greater toxicity and increased cellular uptake.

## Study area

The area where the ZMG is located has a specific type of rock and age. Regionally, the origin of these rocks is mainly associated with volcanic activity and, tectonically, is considered active. To a lesser extent, there is material that has been degraded in situ or transported to lower areas and agglutinated as alluvial rocks.

There are also rhyolite rocks and rhyolitic tuffs containing predominantly paramagnetic minerals. Rocks with low ferromagnesian mineral (FM) content are found west of the city, in the Sierra de La Primavera. In the central part, rocks with a high ferromagnesian mineral content can be found in at least three small volcanic formations of andesite-basalt origin, as well as in the east and south, where the material is basalt or andesite. The Santiago River with FM rocks is located in the northeast. This explains the natural presence of these minerals in the area (Garnica *et al*., 2017).

The AMG has been built on volcanic rocks of different chemical compositions. The most recent ones, associated with the emission of acid tuffs from aerial fall and flow, come from the Sierra de La Primavera (SLP), corresponding to the Pleistocene-Holocene Quaternary, whose age varies from 140,000 to 27,000 years.

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These rocks cover older, thicker rocks (the areas near the SLP with an approximate thickness of 300 m) (Maciel *et al*., 2015) and with less depth (until they practically disappear) towards the area of the Río Grande de Santiago ravine. They originate from older volcanic edifices such as the El Cuatro, Gachupín, and El Tesoro volcanoes.

These rocks were emitted approximately one million years ago (Ma), i.e. in the Pliocene Tertiary, around 8.7 to 13 Ma, and correspond mainly to Miocene andesite and basalt that were emitted by fissures or calderas that are not visible today (Maciel *et al*., 2015).

The different volcanoes and rocks that make them up generate different magnetic responses. To the west, the La Primavera domes (rhyolite and airfall tuffs, a material widely used in construction) respond. These volcanic centres emitted ash that dispersed mainly towards the central part of the ZMG, while in the eastern and southern parts there are volcanic rocks and edifices, such as Cerro del Cuatro (basalt) and its associated volcanoes, Gachupín or Cerro del Tesoro (with a ferromagnetic response, whose material is used for construction), and the very distant Colima volcano (also FM), which is considered active and whose ash has reached the ZMG.

Due to volcanic activity, a thick crust of FM volcanic rocks has formed in the region beneath the most recent layer, which are the products of the SLP. One need only descend to the bed of the Río Grande de Santiago to see that everything that outcrops is volcanic, consisting of older FM rocks, now exposed at the surface, with an approximate age of 5 Ma.

Among the volcanic rocks, we have basalts and andesites, which are lavas that are very fluid at the time of their emission and form cone-shaped volcanic edifices, such as El Cuatro and Gachupín, among others, while other lavas, such as rhyolites, are very acidic and viscous and form domes, such as C. Colli, El Chapulín, and El Tule.

Considering that the last emission of tuffs from the SLP covered the entire area where the urban sprawl has expanded, it is not feasible to superficially appreciate the rocks existing in the subsoil.

This is only possible if the paleotopography is abrupt, as in the case of C. del Cuatro, Gachupín, Cofre de Tesoro, and other small monogenetic volcanic features that were not covered by this ash emission, or if there are faults in this area, such as those observed in Río Santiago or towards the Tesistán area.

The last deposit of FM volcanic rocks in the study area is the ash from the Colima volcano (basic andesites) which historically reached Coahuila and Mexico City in 1913 and 1918, passing through the AMG, and may be present in some of the particles found in this study.

It should be noted that all the rocks mentioned are used in the construction of housing units, factories and land transport routes, so the disintegration and dispersion of the minerals that form the rocks into small particles has probably also been recorded in the study.

Since the end of the 20th century, the Guadalajara metropolitan area (ZMG) has already experienced high levels of pollutants. Toxicity varies considerably depending on the metal that makes up the nanoparticle. For example, it has been determined that copper oxide nanoparticles are significantly more potent in inducing cytotoxicity and DNA damage than titanium dioxide nanoparticles. A key mechanism of toxicity is the dissolution of the nanoparticle, which releases metal ions into the biological medium, which can alter cellular homeostasis and exert direct toxic effects.

In 1996, the ozone ($O_3$) standard was exceeded on 60% of the days of the year and the fine particulate matter ($PM_{10}$) standard on more than 30% of the days. The main pollutants that have been monitored include ozone (O3), carbon monoxide (CO), nitrogen dioxide ($NO_2$), sulphur dioxide ($SO_2$) and suspended particulate matter ($PM_{10}$ and $PM_{2.5}$). Another factor contributing to air pollution in the ZMG is the growth of the vehicle fleet (often old and poorly maintained). Industrial complexes, brick kilns (burning synthetic fuels), deforestation and agricultural burning also contribute.

The ZMG has a high annual average of days with excessive air pollution (up to 150 days of poor air quality per year have been reported). Pollutant levels often exceed local and international standards, including those of the World Health Organisation (WHO).

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## Methodology

The Jalisco Institute of Forensic Sciences (IJCF) was asked to facilitate the observation of samples of main bronchi, first branches, or pulmonary alveoli using SEM technology to search for the presence of particles. The samples were analysed at their facilities and preserved in 2% glutaraldehyde in 1.5 ml Eppendorf tubes.

The sample size was half a square centimetre. The specimens observed corresponded to individuals who had not presented chest injuries and had a low degree of decomposition. A total of 11 individuals who died in 2014 were observed.

Dehydration processes were applied with serial ethanol:

1. Ethanol 40% 1 hour
2. Ethanol 50% 1 hour
3. Ethanol 60% 1 hour
4. Ethanol 70% 1 hour
5. Ethanol 80% 1 hour
6. Ethanol 90% 1 hour
7. Ethanol 100% 1 hour (2x).

Finally, the samples were dried at critical point using Tousimis Samdri 795 equipment. This was the process used to prepare the samples for EDS analysis with Jeol JSM 6610LV equipment, operating at 10kV, with an Oxford Xmax EDS detector and Oxford AZtec software. Observation under the scanning electron microscope was performed with a secondary electron detector. A scanning electron microscopy sample holder was used for mounting, on a double-sided carbon tape substrate. The samples were coated with conductive material (99.9% gold) by sputtering with Denton Vacuum equipment.

## Results

The samples were observed using scanning electron microscopy and elemental mapping analysis, identifying coarse, fine and ultrafine metal particles in human bronchi and lung tissue, as well as fragments of cement, plastic, yeast and bacteria. The similarity between the metal particles identified in the collected samples and those observed in lung tissue warns of latent risks to human health.

The main blood cells observed were erythrocytes, leukocytes, macrophages and platelets. Erythrocytes are the most abundant blood cells in the blood; they are biconcave discs with a diameter of between 6 and 8 µm and a thickness of 2 µm (Jaime *et al*., 2009). Leukocytes are a group of cells that perform various functions, all related to the body's defence against infections and the presence of foreign substances. They are large cells that are classified as granulocytes, lymphocytes, and monocytes. Monocytes are large cells with a diameter of 15 to 20 µm. These cells travel through the blood and reach the connective tissue, where they become macrophages (González de Buitrago, 2010). Platelets are thin discs with a diameter of 2 to 4 µm. They participate in homeostasis, in maintaining vascular integrity and in the blood coagulation process (Conny *et al*., 2011).

Subsequently, through EDS elemental mapping, some elements were identified per individual. The samples with the highest number of elements were individuals 1 and 9 with 12 elements, individuals 4 and 11 with 10 elements, individuals 3 and 12 with 9 elements, individuals 5 and 6 with 8 elements each, individual 2 with 7 elements, and individuals 7 and 10 with 5 elements. The most abundant elements were Al, Pb, As, Hg, and W. The least abundant were Zn, Ta, Nb, Hf, Cu, and Rh (Table and graph 1).

**Box 1**

**Table 1**

Descriptive statistics of the samples

| Statistician | Value | Features |
|---|---|---|
| Population | 11 Individuals | 11 samples. |
| Range | 12−5=7 elements | The difference between the largest and smallest samples is 7 elements. |
| Maximum | 12 elements | Individuals 1 and 9 had the highest number of items. |
| Minimum | 5 elements | Individuals 7 and 10 had the fewest items. |
| Average | 8.82 elements | On average, each sample contained approximately 9 elements. |

*Source: Prepared internally based on research results*

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## Box 2

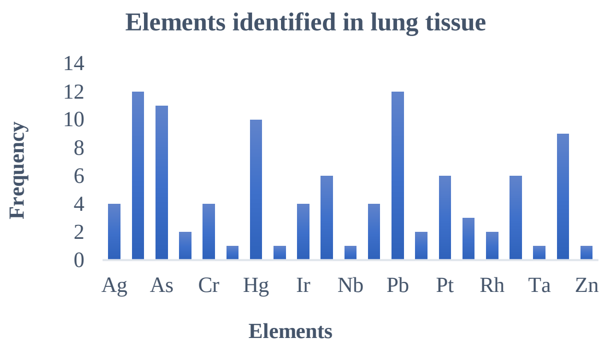


**Figure 1**
Elements identified per individual in lung tissue
*Source: Prepared by the author based on research results*

Once metal nanoparticles cross the lung barrier and reach the bloodstream, they can be distributed to virtually any organ in the body. This systemic dissemination is the cause of a wide range of adverse health effects that go beyond the respiratory system, affecting vital systems such as the cardiovascular and renal systems, and increasing the risk of chronic diseases such as cancer (Hamra, G. B. *et al.* 2014).

The study by Díaz-Gay *et al.* (2025) discusses the genomic mechanisms of lung cancer in non-smokers. The research showed that exposure to high levels of air pollution from $PM_{2.5}$ particles is associated with an increase in somatic mutations, specifically the SBS4 and SBS5 mutational signatures. This finding is of utmost importance, as the SBS4 mutational signature had been associated almost exclusively with genetic damage caused by tobacco. Its presence in non-smokers exposed to air pollution suggests a mutation mechanism and challenges previous models of the causes of lung cancer. This same marker also highlights that there is an association between the accumulation of DNA damage with ageing and exposure.

## Conclusions

The presence of these elements indicates a significant level of pollution in the environment, in addition to the fact that the body's ability to absorb, distribute and excrete these metals varies between individuals.

The metal particles identified in the samples collected and those observed in lung tissue warn of latent risks to human health.

We can infer that when heavy metals are found in the lung, the main route of entry was the air (dust, fumes, aerosols). This has direct implications for health. Chronic exposure to lead (Pb), arsenic (As) and mercury (Hg) through inhalation is associated with pulmonary fibrosis, inflammation, damage to the alveoli and risk of lung cancer (especially arsenic). In the case of tungsten (W), dust from this element has been associated with interstitial lung disease and fibrosis. Its presence alongside other metals suggests a common source of dust or fume contamination.

In general terms, Al, Pb, As, Hg and W are causing the direct toxic load on the respiratory system of the tissues observed.

Possible causes could include waste burning, industrial processes, smelter emissions, or dust particles raised by erosion, mining, or brickworks. It should be remembered that, due to their small size, NPs are deposited deep in the pulmonary alveoli and can even travel into the bloodstream, spreading to other organs.

Table 2 shows the elements identified in the samples and the possible health effects that may occur.

## Box 3

**Table 2**
Identified elements and possible health effects

| Element | Main Source of Toxicity | Specific Health Issues |
|---|---|---|
| Lead (Pb) | Neurotoxicity and accumulation. | Damage to the central nervous system (mainly in children), hypertension, anaemia, and chronic renal failure. |
| Arsenic (As) | Known carcinogen. | Lung, bladder, and skin cancer. It affects the cardiovascular system and can cause neuropathy. |
| Mercury (Hg) | It vaporises and passes through barriers. | Neurotoxicity (tremors, cognitive impairment), kidney damage, and effects on foetal development. |
| Aluminium (Al) | Irritation and pulmonary fibrosis. | It may cause pneumoconiosis (aluminosis lung disease) after prolonged exposure to high doses, which may affect lung function. |

| | | |
|---|---|---|
| Tungsten (W) | Carcinogenic potential. | Its toxicity has been less studied, but it has been associated with carcinogenic potential and pulmonary and renal toxicity in occupational studies. |
| Chrome (Cr) | Carcinogenic (Hexavalent Chromium). | Lung cancer, respiratory tract irritation, and contact allergies. |
| Copper (Cu) | Induction of oxidative stress. | In high concentrations, it can damage the liver and kidneys, as well as irritate the respiratory tract. |
| Cinc (Zn) | Metal fume fever. | Although essential, inhalation of ZnO NPs can cause "metal fume fever" and oxidative stress. |
| Platinum Group Metals (Pt, Rh, Os, Re) | Sensitisation and irritation. | Associated with occupational allergies and asthma, mainly in refinery workers or those working near catalytic converters. (by Pt and Rh). |

*Source: (EPA 2017; ATSDR 2016e; Royal Society of Chemistry 2017; Lenntech 2016; QuimiNet.com 2011)*

It is important to note that NPMs act as vehicles for metals whose carcinogenicity is well defined. Hexavalent chromium (VI) and nickel, common components in the welding fumes mentioned above, are classified by the International Agency for Research on Cancer (IARC) as Group 1 carcinogens (carcinogenic to humans).

Some of the main roads in the ZMG have high traffic flow, which circulates constantly and is associated with an increased risk of respiratory diseases and lung cancer. There are criteria that indicate that a range of 4,000 to 10,000 vehicles per day is a common threshold for considering a road to be high-volume and, therefore, a significant source of pollution from particulate matter ($PM_{2.5}$) and metal nanoparticles, such as those generated by brake and tyre wear and exhaust fumes. Therefore, the risk of developing lung cancer and other respiratory diseases increases significantly when living within a radius of 300 to 500 metres of roads that exceed these high traffic flow thresholds (Querol, 2008; Raaschou-Nielsen *et al.*, 2013; Jerrett *et al.*, 2013).

## Declarations

### Conflict of interest

The authors declare that they have no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this paper.

### Contribution of authors

*Peña García Laura Elizabeth* Contributed to the project idea, research method and technique.

### Availability of data and materials

The data obtained in this research are available.

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### Abbreviations

| | |
|---|---|
| NPs | Nanoparticles |
| MP | Particulate material |
| $PM_{2.5}$ | Particles with a diameter smaller than 2.5 µm |
| $PM_{0.1}$ | Particles with a diameter smaller than 0.1 µm |
| $PM_{10}$ | Particles with a diameter smaller than 10 µm |
| NPM | Metal nanoparticles |
| ENT | Non-communicable diseases |
| EPOC | Chronic obstructive pulmonary disease |
| ZMG | Guadalajara metropolitan area |
| IARC | Cancer research |
| SLP | Sierra La Primavera |
| Ma | Millions of years |

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