Microplastics in air: Are we breathing it in?

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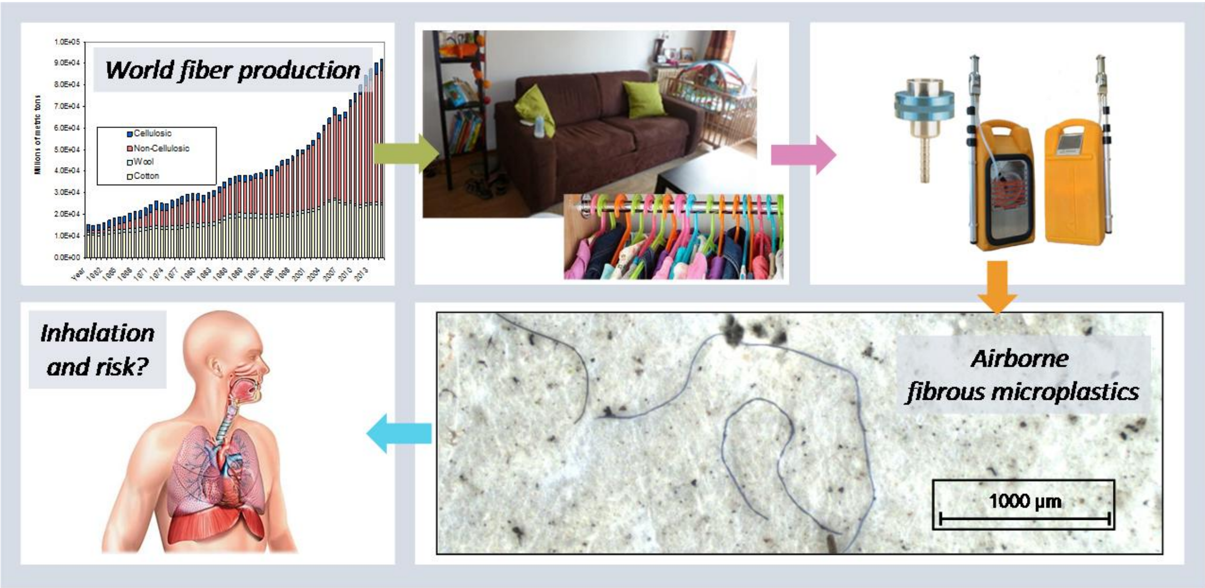
1. ABSTRACT

The annual production of plastic fibers increased by more than 6% per year, reaching 60 million metric tons, about 16% of the world plastic production. The degradation of these fibers produces microfragments. Such micro fibers have been observed in atmospheric fallouts, as well as in indoor and outdoor environments. Fibrous MPs may be inhaled. Most of them are likely to be subjected to mucociliary clearance; some, however, may persist in the lung causing localized biological responses, including inflammation, especially in individuals with compromised clearance mechanisms. Associated contaminants, like PAH, could desorb and lead to genotoxicity while the plastic itself and its additives (dyes, plasticizers) could lead to health effects including reproductive toxicity, carcinogenicity and mutagenicity.

2. GRAPHICAL ABSTRACT



3. HIGHLIGHTS

- More than 60 million metric tons of plastic fibers were produced in 2016
- Microplastic fibers fragments are present in outdoor and indoor air
- The inhalation of airborne fibrous microplastics is a question of size
- Those inhaled fibrous microplastics may be durable and are likely to persist
- Airborne fibrous microplastics may also carry pollutants

KEYWORDS

- Fibers
- Microplastics
- Air pollution
- Health risk
- Inhalation
- Micropollutants

1. INTRODUCTION

Plastic pollution is an emerging concern worldwide, with the majority of studies focusing on microplastics (MPs; plastic particles with a longest dimension < 5 mm) in marine, and more recently, continental environments. Whilst the ubiquity of MPs, and especially of fibrous MPs in both marine and freshwater ecosystems has been demonstrated, the dynamics of their sources, pathways and reservoirs are not well documented. Indeed, until recently, the presence of airborne MPs and associated health risks has not been adequately studied. This paper addresses both issues by reviewing work undertaken on the occurrence of MPs in the atmospheric compartment as well as discussing human exposure and the potential for subsequent health risks.

2. OCCURRENCE OF MICROPLASTICS IN THE ATMOPHERIC COMPARTMENT

2.1. Airborne MPs: is there an issue?

Worldwide plastic production increases annually by approximately 3%, and, excluding plastic fiber production, reached 322 million metric tons in 2016 [1]. More than 60 million metric tons of plastic fibers (also called synthetic fibers, Table 1) were produced in 2016 – two thirds of the worlds fiber production, representing a yearly growth rate of about 6.6% over the last decade. Other fibers include cellulosic fibers (6%) and natural fibers (27%, mainly cotton) [2].

Table 1: Simplified classification of fibers

Natural Fibers		Man-made Fibers	
Vegetal	Animal	Cellulosic Fibers	Synthetic Fibers
Cotton, flax, etc.	Wool, silk, etc.	Viscose/rayon, acetate, etc.	Polypropylene, acrylic, polyamide, polyester, polyethylene

The commercial use of fine-diameter (1 – 5 µm) plastic fibers has increased, such as in the sports clothing industry [3]. These small fibers may be shed and released as the clothing wears or during washing [4,5] and drying . Furthermore, the industrial chopping or grinding of synthetic material can result in respirable aerosol formation. Furthermore fibrous MPs too large for inhalation may undergo photo-oxidative degradation in the environment, along with wind shear and/or abrasion against other ambient particulates, and may eventually fragment into particles with respirable aerodynamic diameters. Fibrous MPs can also settle on the floor and children – indeed owing to crawling and frequent hand-to-mouth contact, are daily ingesting settled dust. The risk of inhaling fibrous MPs following widespread contamination within different environmental compartments deserves special attention owing to both the scale of worldwide production and their potential to fragment into smaller, more bioavailable fibers. The human exposure to MPs can occur also through ingestion.

2.2. Can we find fibrous microplastics in the atmosphere?

To date, and to the best of our knowledge, only two studies have demonstrated the presence of fibrous MPs in the atmospheric compartment [6,7], thereby suggesting potential human exposure. An earlier study [8] highlighted the existence of respirable organic fibers in the indoor and outdoor environment but did not discriminate between natural and synthetic materials. Whilst other studies have suggested the occurrence of atmospheric MPs , no direct evidence was provided [9,10].

Dris *et al.* (2016) evaluated the presence of fibrous MPs in total atmospheric fallout (TAF - including dry and wet deposition) at one urban site and one suburban site in the Paris Megacity [5]. TAF was collected continuously on the roofs of buildings. Fibrous material accounted for almost all of the material collected (Figure 1), the remaining being rare small plastic fragments (smaller than 100 µm). Based on a 1-year and a 6-month monitoring period, respectively on two sites, atmospheric fallout of between 2 and 355 fibers/m^2/day was calculated. TAF fluxes were systematically higher at the urban site than at the suburban one, probably linked to the density of the surrounding population. Rainfall also appears to be an important factor influencing the fallout flux. Despite no significant quantitative correlation between the concentrations of fibers and the characteristic of the rain events (rainfall depth, intensity, etc.), TAF during wet weather periods are always substantially larger that during dry weather periods.

2.3. What are the characteristics atmospheric fibrous microplastics ?

After chemical characterization, it appeared that 29% of the fibers evaluated in TAF are plastic, with the majority constituting cellulosic or natural origin [5]. The length distribution of fibers collected larger than 50 µm was assessed. On measuring fiber length, smaller size classes [200-400 µm] and [400 – 600 µm] were predominant whilst fibers in the larger size ranges were rare. Few fibers measuring between 50 µm (observation limit) and 200µm in length have been detected. The diameter of the fibers varied mainly between 7 and 15 µm.

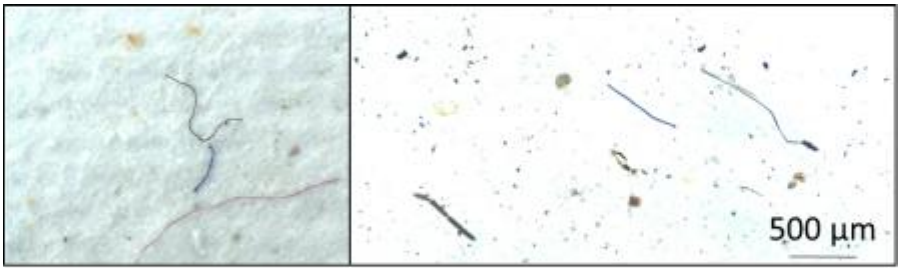


Figure 1: fibrous microplastic observed in atmospheric fallout

2.4. Are we exposed to airborne fibrous microplastics?

Dris *et al.* (2017) investigated fibers in indoor and outdoor air, as well as indoor settled dust [6]. Three indoor sites comprising two apartments and one office were selected within a dense urban area of Paris. Outdoor air was sampled in close proximity to the office site, which was also where TAF monitoring took place. A pump sampled 8 L/min of indoor air onto quartz fiber filters (1.6 µm). Sampled volumes varied depending on occupants' presence. The same method was used for the assessment of outdoor air. Overall, indoor concentrations ranged from 1.0 to 60 fibers.m^{-3}. Outdoor concentrations were significantly lower, ranging between

0.3 and 1.5 fibers.m^{-3}. The deposition rate of the fibers in the indoor environments ranged between 1,586 and 11,130 fibers.d^{-1}.m^{-2}. Settled dust was collected using a conventional vacuum cleaner and analysis revealed a concentration of fibers ranging from 190 to 670 fibers/mg.

2.5. What are the characteristics of fibrous microplastics in indoor environments?

According to chemical characterization, 67% of indoor fibers were made of natural material, primarily cellulosic, while the remaining 33% fibers contained petrochemicals with polypropylene being predominant [6]. A similar size distribution was determined for indoor air, outdoor air and TAF with slight differences. These differences between compartments lie in the size of the longest observed fibers: while fibers in the range of 4,650-4,850 µm can be found in dust fall, no fiber longer than 3,250 µm is observed in indoor air almost the double of the size of the longest fibers in outdoor air (1,650 µm). Larger fibers are observed in dust fall because they settle more rapidly and accumulate on the floor. While fibers under 50 µm were not counted due to the observation lower limit, the size distribution pattern suggests that much smaller fibers might be present.

3. **IMPACTS ON HUMAN HEATH?**

3.1. Are airborne fibrous microplastics breathable?

The likelihood that airborne fibrous MPs enter our respiratory system will be dependent upon size. First, it is important to discriminate between the terms inhalable and respirable. Particles and fibers able to enter the nose and mouth and deposit in the upper airway are inhalable, whilst those able to reach and deposit in the deep lung are respirable. Deposition in the airway is a function of aerodynamic diameter and within the respiratory zone, deposition falls off above 5 µm diameter [11].

The World Health Organisation defines a fiber as any particle that has a length > 5 µm, with a diameter < 3 µm and an aspect (length-to-diameter) ratio > 3:1 [12]. Fibrous MPs that exceed these criteria may be inhaled, but are likely to be subjected to mucociliary clearance in the upper airways, leading to gastro-intestinal exposure. Some fibrous MPs may however avoid the mucociliary clearance mechanisms of the lung, especially in individuals with compromised clearance mechanisms.

3.2. Do fibrous microplastics accumulate in the human body?

Another factor contributing to toxicity is the biopersistence of inhaled fibrous MPs, which is related to durability in and clearance from the lung [13]. *In vitro* tests have found plastic fibers to be extremely durable in physiological fluid: polypropylene, polyethylene and polycarbonate fibers showed almost no dissolution or changes to surface area and characteristics in a synthetic extracellular lung fluid after 180 days. This suggests plastic fibers are durable and likely to persist in the lung [14]. Biopersistence is also connected to length, with longer fibers more likely to avoid clearance [3].

Plastic fibers have been observed in pulmonary tissue [15], suggesting that the human airway is of a sufficient size for plastic fibers to penetrate the deep lung. Histopathological analysis of lung biopsies from workers in the textile (polyamide, polyester, polyolefin, and acrylic) industry showed foreign-body-containing granulomatous lesions, postulated to be acrylic, polyester, and/or nylon dust [16]. These observations confirm that some fibers avoid clearance mechanisms and persist.

3.3. Occupational health risks

Studies among nylon flock (fiber) workers suggest there is no evidence of increased cancer risk, although workers had a higher prevalence of respiratory irritation [3]. Interstitial lung disease is a work-related condition that induces coughing, dyspnoea (breathlessness), and reduced lung capacity in workers processing either para-aramid, polyester, and/or nylon fibers [17–19]. Workers also present clinical symptoms similar to allergic alveolitis [16]. These health outcomes are indicative of the potential for MPs to trigger localised biological responses, given their uptake and persistence.

Whilst these effects are distinct from those seen after asbestos exposure, the legacy of asbestos toxicology can in-part help predict health effects of fibrous MPs. In silicate-based fibers, length and biopersistence in the airway/lung are the characteristics that govern toxicity and the mechanisms of that toxicity. Whether the same is true for fibrous MPs remains to be determined.

3.4. What are the potential mechanisms of toxicity?

3.4.1. Particle Effects: Inflammation and Secondary Genotoxicity

Beyond a certain exposure level/dose, all fibers seem to produce inflammation following chronic inhalation [13]. The general paradigm for fibrous particle toxicity, based on asbestos and manmade vitreous fibers is that upon cell contact, intracellular messengers and cytotoxic factors are released leading to lung inflammation, and potentially secondary genotoxicity following the excessive and continuous formation of reactive oxygen species (ROS). Fibrosis, and in some cases cancer, can manifest after prolonged inflammation [13]. Toxicity is greater for longer fibers [13] as they cannot be adequately phagocytosed, stimulating cells to release inflammatory mediators [20] that contributes to fibrosis.

Poorly-soluble low-toxicity particles have been found to cause lung tumours and inflammation in rats ([21], however information on whether this translates to humans is lacking. Plastic is typically considered inert, yet its biopersistence and the shape of fibrous MPs could lead to inflammation.

3.4.2. Chemical Effects

3.4.2.1 Associated Contaminants

Airborne fibrous MPs may carry pollutants adsorbed from the surrounding environment due to their hydrophobic surface [22]. In urban environments, where they co-occur with traffic emissions, they may carry polycyclic aromatic hydrocarbons (PAHs) and transition metals.

Detrimental pulmonary outcomes could then ensue following desorption of associated contaminants leading to primary genotoxicity amongst other effects. For example, stable and unstable DNA lesions may arise after metabolism of fibrous-MP-associated PAHs [13].

3.4.2.2 Intrinsic Contaminants

Plastic may contain unreacted monomers, additives, dyes and pigments, many of which could lead to health effects including reproductive toxicity, carcinogenicity and mutagenicity [23], should they leach or volatilize and accumulate. For example, the contamination of house settled dust with polybrominated diphenyl ethers [23–25] or phthalates [26] is widely documented worldwide, possibly owing to emissions from fibrous MPs resulting from the wear of plastic household textiles.

4. RECOMMENDATIONS

There is an urgent need for data on the human health impacts of fibrous MPs. However, before this is determined, it is important to better assess whether and if so, how we are exposed. To this end, collaboration between environmental, epidemiological and air quality communities is required to set up a relevant research programme, which will include a specific monitoring strategy. Both length and diameter should be included when reporting on the presence of MPs since diameter is crucial to respirability, whilst length plays an important role in persistence and toxicity. The full spectrum of fibers (both natural and petrochemical-based structures) must also be considered. Within the studies conducted to date, the limit of observation was 50 µm but detection at a smaller scale (< 10 µm) is crucial. The potential of inhaling these fibers must also be determined and all potential impacts urgently identified.

5. **REFERENCES**

Papers of special interest (•) [3,11]
Papers of outsanding interest (••) : [6,7]

1. PlasticsEurope: Plastics - the Facts 2016, An analysis of European latest plastics production, demand and waste data. *Plast. Eur. Assoc. Plast. Manuf. Bruss. P40* 2016, [no volume].

2. ICAC: *World Textile Demand - May 2017*. 2017.

3. Warheit DB, Hart GA, Hesterberg TW, Collins JJ, Dyer WM, Swaen GMH, Castranova V, Soiefer AI, Kennedy GL: Potential Pulmonary Effects of Man-Made Organic Fiber (MMOF) Dusts. *Crit. Rev. Toxicol.* 2001, 31:697–736.

4. Cesa FS, Turra A, Baruque-Ramos J: Synthetic fibers as microplastics in the marine environment: A review from textile perspective with a focus on domestic washings. *Sci. Total Environ.* 2017, 598:1116–1129.

5. Napper IE, Thompson RC: Release of synthetic microplastic plastic fibres from domestic washing machines: Effects of fabric type and washing conditions. *Mar. Pollut. Bull.* 2016, 112:39–45.

6. Dris R, Gasperi J, Saad M, Mirande C, Tassin B: Synthetic fibers in atmospheric fallout: A source of microplastics in the environment? *Mar. Pollut. Bull.* 2016, 104:290–293.

7. Dris R, Gasperi J, Mirande C, Mandin C, Guerrouache M, Langlois V, Tassin B: A first overview of textile fibers, including microplastics, in indoor and outdoor environments. *Environ. Pollut.* 2017, 221:453–458.

8. Schneider T, Burdett G, Martinon L, Brochard P, Guillemin M, Teichert U, Draeger U: Ubiquitous fiber exposure in selected sampling sites in Europe. *Scand. J. Work. Environ. Health* 1996, 22:274–284.

9. Free CM, Jensen OP, Mason SA, Eriksen M, Williamson NJ, Boldgiv B: High-levels of microplastic pollution in a large, remote, mountain lake. *Mar. Pollut. Bull.* 2014, 85:156–163.

10. Waller CL, Griffiths HJ, Waluda CM, Thorpe SE, Loaiza I, Moreno B, Pacherres CO, Hughes KA: Microplastics in the Antarctic marine system: An emerging area of research. *Sci. Total Environ.* 2017, 598:220–227.

11. Donaldson K, Tran CL: Inflammation caused by particles and fibers. *Inhal. Toxicol.* 2002, 14:5–27.

12. WHO: Determination of airborne fibre number concentrations : a recommended method, by phasecontrast optical microscopy (membrane filter method). 1997, [no volume].

13. Greim H, Borm P, Schins R, Donaldson K, Driscoll K, Hartwig A, Kuempel E, Oberdorster G, Speit G: Toxicity of fibers and particles report of the workshop held in Munich, Germany, October 26-27, 2000. *Inhal. Toxicol.* 2001, 13:737–754.

14. Law BD, Bunn WB, Hesterberg TW: Solubility of Polymeric Organic Fibers and Manmade Vitreous Fibers in Gambles Solution. *Inhal. Toxicol.* 1990, 2:321–339.

15. Pauly JL, Stegmeier SJ, Allaart HA, Cheney RT, Zhang PJ, Mayer AG, Streck RJ: Inhaled cellulosic and plastic fibers found in human lung tissue. *Cancer Epidemiol. Biomarkers Prev.* 1998, 7:419–428.

16. Pimentel JC, Avila R, Lourenço AG: Respiratory disease caused by synthetic fibres: a new occupational disease. *Thorax* 1975, 30:204–219.

17. Boag AH, Colby TV, Fraire AE, Kuhn C, Roggli VL, Travis WD, Vallyathan V: The pathology of interstitial lung disease in nylon flock workers. *Am J Surg Pathol* 1999, 23:1539–45.

18. Eschenbacher WL, Kreiss K, Lougheed MD, Pransky GS, Day B, Castellan RM: Nylon Flock–Associated Interstitial Lung Disease. *Am. J. Respir. Crit. Care Med.* 1999, 159:2003–2008.

19. Kremer AM, Pal TM, Boleij JS, Schouten JP, Rijcken B: Airway hyper-responsiveness and the prevalence of work-related symptoms in workers exposed to irritants. *Am J Ind Med* 1994, 26:655–69.

20. Ye J, Shi X, Jones W, Rojanasakul Y, Cheng N, Schwegler-Berry D, Baron P, Deye GJ, Li C, Castranova V: Critical role of glass fiber length in TNF-α production and transcription factor activation in macrophages. *Am. J. Physiol. - Lung Cell. Mol. Physiol.* 1999, 276:L426–L434.

21. Borm PJA, Höhr D, Steinfartz Y, Zeitträger I, Albrecht C: Chronic Inflammation and Tumor Formation in Rats After Intratracheal Instillation of High Doses of Coal Dusts, Titanium Dioxides, and Quartz. *Inhal. Toxicol.* 2000, 12:225–231.

22. Endo S, Yuyama M, Takada H: Desorption kinetics of hydrophobic organic contaminants from marine plastic pellets. *Mar. Pollut. Bull.* 2013, 74:125–131.

23. Linares V, Bellés M, Domingo JL: Human exposure to PBDE and critical evaluation of health hazards. *Arch. Toxicol.* 2015, 89:335–356.

24. Fromme H, Hilger B, Kopp E, Miserok M, Völkel W: Polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCD) and “novel” brominated flame retardants in house dust in Germany. *Environ. Int.* 2013, 64:61–68.

25. Rauert C, Harrad S, Suzuki G, Takigami H, Uchida N, Takata K: Test chamber and forensic microscopy investigation of the transfer of brominated flame retardants into indoor dust via abrasion of source materials. *Sci. Total Environ.* 2014, 493:639–648.

26. Sukiene V, von Goetz N, Gerecke AC, Bakker MI, Delmaar CJE, Hungerbuhler K: Direct and Air-Mediated Transfer of Labeled SVOCs from Indoor Sources to Dust. *Environ. Sci. Technol.* 2017, 51:3269–3277.