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Need for assessing the inhalation of micro(nano)plastic debris shed from masks, respirators, and home-made face coverings during the COVID-19 pandemic☆

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The transmission of the novel coronavirus (SARS-CoV-2) is primarily through respiratory droplets and fomites (WHO, 2020a), and potentially aerosols (World Health Organization WHO, 2020). As of September 19, there have been more than 30 million confirmed cases of infections around the globe. Without an effective vaccine in place, masks, respirators, and various types of face coverings remain the most accessible means of respiratory protection for the public during the current pandemic. With proven efficacy in barring the inhalation of airborne pathogens, medical face masks and respirators manufactured to industrial standards are highly effective in filtering respirable virus carriers. Consensuses from existing scientific studies suggest that airborne transmission could play an important role in the spread of COVID-19 (Morawska and Milton, 2020). Regulatory bodies and organizations have since advocated the use of personal respiratory protection in public settings where adequate physical distancing cannot be achieved (Centers for Disease Control and Prevention CDC, 2020; NHC, 2020; WHO, 2020a). In an effort to conserve critical supplies for healthcare workers and medical first responders, the U.S. Centers for Disease Control and Prevention (CDC) recommends the public to wear cloth face coverings as substitutes for masks and respirators (Centers for Disease Control and Prevention CDC, 2020). These home-made cloth masks, if properly made and worn, can provide significant protection against airborne pathogens (Konda et al., 2020; Zhao et al., 2020).

Where accessible, medical face masks, or variations of these (*e.g.*, surgical or procedure masks), could offer the most viable option for the general public (NHC, 2020; WHO, 2020). These typically have a three-ply structure consisting of a non-woven outer layer, a melt-blown middle layer functioning as an electret air filter, and a non-woven inner layer in contact with the user's mouth and nose. In a typical contemporary design, all three layers are made by polypropylene, a common type of petroleum-based plastic. Deformable nose strips and elastic ear bands are integrated as standard accessories to ensure a proper fit. These are light, flexible, and comfortable to wear, offering a good balance between filtration efficiency, cost, and ease of breathing. Compared with Filtering Facepiece Respirators (FFRs, *e.g.*, N95 respirators) which generally have higher ratings in filtration efficiency, they offer effective protection at only a fraction of the cost (generally <20%) and can be worn for longer periods of time without having difficulty in breathing. Specifically, the FDA warned the risks of wearing N95 respirators for people with chronic respiratory, cardiac, or other medical conditions that make breathing difficult and, because a proper fit cannot be achieved on children or people with facial hair, N95 respirators are not suitable for them to wear (FDA, 2020a).

Current quality standards on medical masks and respirators regulate performance requirements and testing methods. With respect to the former, thresholds have been imposed on filtration efficiency (bacterial and particulate), fluid resistance, pressure

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drop, and flammability. Ethylene oxide, a common sterilization agent used for disinfecting medical devices, including many sterile medical face masks sold in the domestic market in China and recently the decontamination of used surgical respirators in the U.S. (FDA, 2020b), is also regulated with strict limits on its residuals (ISO, 2008). There seems to be, however, an important piece missing in the suite of standards and volumes of research on inhalable environmental contaminants. None of these standards, including the ASTM standards (F1862, F2100, F2101, F2299) and NIOSH regulation (42 CFR 84), which are adopted by the FDA in regulating medical face masks and surgical respirators in the U.S. (FDA, 2020a), regulate respirable debris such as micro(nano)plastics that may be present in these products. In fact, such neglect is not unique to US standards: a review of current ISO standards (ISO 22609, 16900), EU standards (EN 140, 143, 149, 14683) and Chinese standards (GB 19083, 2626; GB/T 32610, 38880; YY 0469; YY/T 0969) on masks and respirators found no information pertinent to this particular type of hazard. With these becoming a necessity for many in their daily life and work, questions must be raised over this apparent regulatory gap concerning their long-term use safety. This is especially important given that there is already a growing body of evidence on the inhalation of micro(nano)plastics and their adverse effects in humans and animals (Prata, 2018).

Contrasting to the extensive work on assessing their efficacy in filtering airborne particulates, very little attention has been drawn to this issue. While the multi-ply structure is deliberately designed for filtering droplets, aerosols, and fine particulates in air drawn from *outside*, the risk of inhaling plastic microfibers, particles, and fragments from the *inside* of masks and respirators has only been anecdotally examined. An early study by Howie et al. (1986) found significant amounts of respirable microfibers, with diameters <3 μm and lengths >5 μm and in the order of 0.1 to >200 per mL, shed from some respirators supplied for occupational use. It should be noted that the study targeted FFRs, a type of respiratory protection device similar to their contemporary counterparts but without the electret filter in between. Since the design has changed substantially for FFRs, the applicability of their finding is under question on contemporarily made respirators. By putting several top-selling medical face masks and N95 respirators under microscopes, however, we saw abundant loosely attached debris on their inner facings, some showing the morphology of fibers and others as particles, in the micron and sub-micron ranges (Fig. 1). These could be either self-carried, or contaminants during their manufacturing process, or even from their plastic packaging – most of the products were packed in plastic bags to maintain sterility. While more rigorous studies are undoubtedly needed, these images offer a glimpse of the issue. With an ongoing shortage from the major suppliers and a myriad of products with countless brands currently offered in the market, it seems inevitable that some products would present similarly, if not more, abundant respirable debris, given that there is no such regulation in place. Whether these plastic debris could cause stress and inflammation in the human respiratory tract and exacerbate vulnerability to viral infection is a further question that warrants investigation (Qu et al., 2020).

A special note must be given on home-made cloth face coverings. For fabrics repurposed as face masks, as per the current guidelines by the CDC (Centers for Disease Control and Prevention CDC, 2020), debris is likely to be generated from cutting and tearing. Some fabrics, such as velvets, fleeces and towels, are known to shed microfibers when disturbed (Prata, 2018). Detergent residues and lint generated from machine laundering and tumble drying may also be present as inhalable contaminants in washed garments (Leverette, 2019; Prata, 2018; Wright and Kelly, 2017). Some household items including vacuum bags, paper towels, and toilet tissues have been suggested as bulk layers or additional filters in making face coverings (WHO, 2020a; Zhao et al., 2020). While they may be beneficial in improving the filtration efficiency, one must keep in mind that these are not designed to be free of loose materials, and therefore may shed inhalable debris as air is drawn through. As an initial screening, materials showing visible signs of shedding should be avoided when making face coverings. Further, complaints of throat irritation or discomfort in the respiratory tract by children, the elderly, or other sensitive individuals after wearing these may be alerting signs of excessive amounts of respirable debris inhaled from self-made masks and respirators (Howie et al., 1986; Prata, 2018).

With numbers continue to rise in many parts of the world, COVID-19 has no ending yet in sight. While the virus still looms in our communities, wearing respiratory protection could become a norm for many in their daily life and work. Respirable hazards such as micro(nano)plastics present in these may escalate from once an occupational hazard to a public health issue. As a quickly expanding research domain, researchers studying the inhalation of micro(nano)plastics through atmospheric or anthropogenic sources are now facing the reality that there is a piece of plastic garment on top of the mouth and nose for millions of people every day. While no methodologies are offered in current standards for carrying out such tests, preliminary assessments of this type do not require complex apparatus or experimentation. For environmental scientists, there is perhaps no need to look further beyond their own field. For a quantitative assessment, the conventional air-drawing method followed by microfiltration membrane retention reported by Vianello et al. (2019) and Howie et al. (1986) should be adequate and easy to adopt. Other techniques such as the Scanning Mobility Particle Sizer (SMPS) and Aerodynamic Particle Sizer (APS) spectrometers offer the advantages of automated, real-time measurement of airborne particle size distribution, which have been used for estimating the inhalation of cosmetic powers (Nazarenko et al., 2012). Whenever needed, professional-grade breathing simulators are commercially available, which can provide accurate and flexible control over a range of operating parameters to mimic different patterns of human breathing (EPA, 2011). Breathing patterns and exposure time should be studied as key variables to account for differences in people wearing masks, respirators, or face coverings. When carrying out such work, one needs to be careful not to dismantle their intact structure. Any tearing or splitting of the layers is likely to generate artificial debris (Sobhani et al., 2020). Ideally, the assessment can be done on intact, uncontaminated items worn on manikins, with the entire set-up placed in a laminar flow bench to avoid contaminants in the ambient air. Studies identifying the chemical composition and prevalence of the debris will be particularly useful in tracing the origin of these contaminants, which may be of emerging concerns given their widespread use during the current pandemic and possibly the post-pandemic era. For this purpose, techniques that are currently employed for studying micro(nano)plastics in environmental matrices (Fu et al., 2020; Li et al., 2020; Mai et al., 2018, 2019), including Fourier transform infrared spectroscopic imaging (FTIR imaging), micro-Raman spectroscopy (μ-Raman), and pyrolysis-gas chromatography/mass Spectrometry (Py-GC/MS) can be particularly useful in characterizing the breathable debris present in masks and respirators. Going further, investigations will need to be done on whether the debris will cause stress or inflammation in human respiratory tract and exacerbate vulnerability of viral infection. We also wish to point out the importance of putting the prospective data into context in future efforts assessing such exposure. Specifically, one must compare the quantities of intake and effects of such intake with other common environmental sources of micro(nano)plastics (Prata, 2018; Wright and Kelly, 2017) to assess the relative significance via this particular route of exposure. When

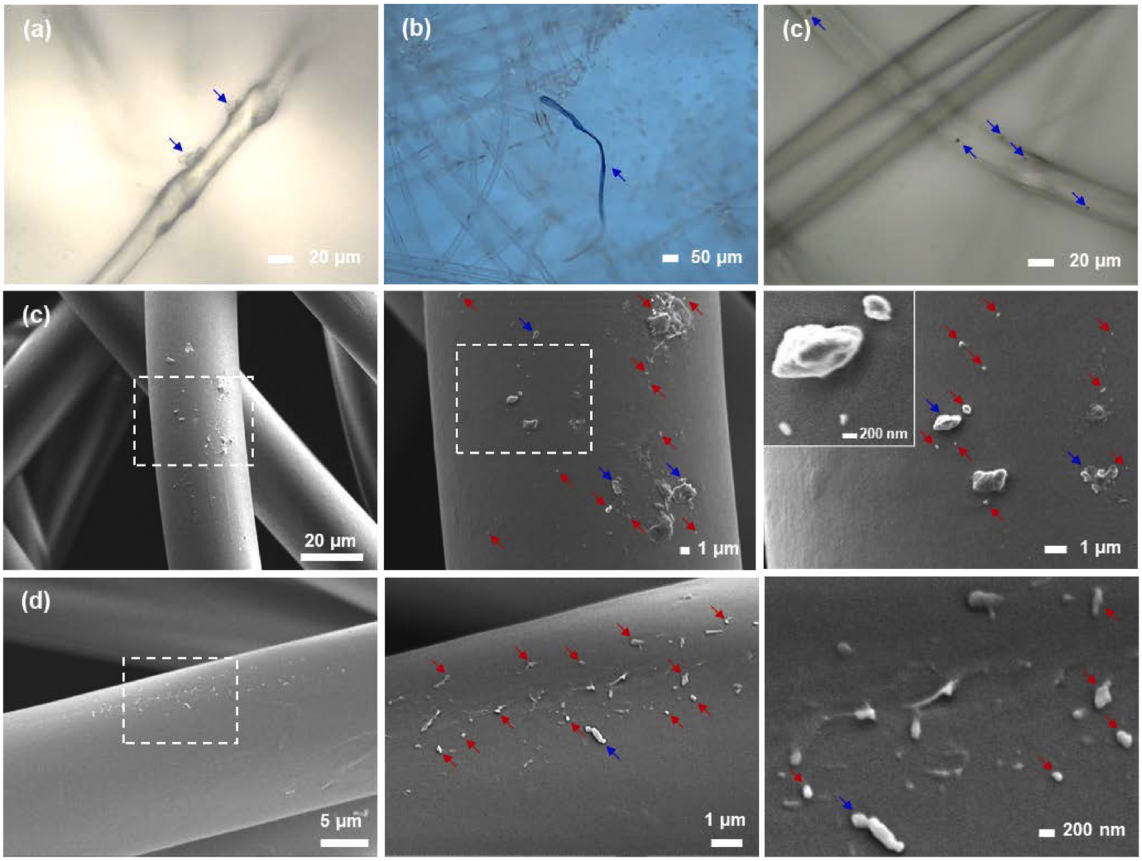

Fig. 1. Optical and scanned electron microscopy images on top-selling medical face masks (a) (b) (d) and a particulate respirator (c) in mainland China. Images were acquired on the inner facing of each sample product. Scale bars were re-drawn for clarity. Fibers, fragments, and particles in micro- and nanosized ranges were abundant and loosely attached on the structural fibers of the products. Blue arrows denote microsized fibers, fragments, and particles. Red arrows denote particles and fragments in the sub-micron (<1 μm) and nanosized (<100 nm) range. Additional images, methods, QA/QC, and discussions can be found in the Supplementary Data. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

weighing the risks and benefits, one must also factor in the reality that without safe, effective and publicly accessible immunizations, these remain the most practical means of respiratory protection in settings with high risks of virus transmission. Any findings, should they be propagated in an untruthful or non-rigorous form to the public, may impose negative effects on the acceptance of masks and respirators, during the current or future pandemic caused by respiratory pathogens. Thus, findings must be interpreted with caution and advice should be given on a situation-by-situation basis. In the meantime, we call for collaborative efforts from scientists, manufacturers, and regulators to assess such risks and look for viable methods to reducing micro(nano)plastics and other respirable debris in face masks and respirators worn by a large population worldwide during the current pandemic.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envpol.2020.115728.

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