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High-efficiency particulate air (HEPA) filters in the era of COVID-19: function and efficacy

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Abstract

Aerosol generating procedures (AGPs) in the office represent a major concern for healthcare-associated infection (HAI) of patients and healthcare providers by SARS-CoV-2, the causative agent for Coronavirus disease 2019 (COVID-19). Although the Centers for Disease Control and Prevention has not provided any recommendations for the use of portable air purifiers, air purifiers with high-efficiency particulate air (HEPA) filters have been discussed as an adjunctive means for decontamination of SARS-CoV-2 aerosols in healthcare settings. This commentary discusses HEPA filter mechanisms of action, decontamination time based on efficiency and flow rate, theoretical application to SARS-CoV-2, and limitations. HEPA filter functionality and prior CDC guidance for SARS-CoV-1 suggest theoretical efficacy for HEPA filters to decontaminate airborne SARS-CoV-2, although direct studies for SARS-CoV-2 have not been performed. Any portable HEPA purifier utilization for SARS-CoV-2 should be considered an adjunctive infection control measure, and undertaken with knowledge of HEPA filter functionality and limitations in mind.

Introduction

Airborne transmission of the Severe Acute Respiratory Syndrome coronavirus 2 (SARS-CoV-2), the causative agent of the Coronavirus disease 2019 (COVID-19), occurs through respiratory droplets (generally >5 microns) and aerosol droplets (generally <5 microns) that are expectorated from respiratory tracts of infected individuals.[1] Aerosol generating procedures (AGPs) represent a major concern for healthcare-associated infection (HAI) of patients and healthcare providers. In comparison to large droplets, which are rapidly pulled downwards by gravity, aerosols may remain suspended in the air for an hour or more.[2] Otolaryngology is one medical specialty at particularly high risk of HAI with SARS-CoV-2 due to commonplace performance of AGPs in the office. Current guidance by the Centers for Disease Control and Prevention (CDC) is that AGPs be performed in airborne infection isolation rooms (AIIR; i.e. negative pressure rooms) when possible or otherwise allowing procedure rooms to remain unoccupied until SARS-CoV-2-laden aerosols may be cleared through other means, e.g. room air exchanges from indwelling ventilation.[3] The CDC has not provided any recommendations for the use of portable air purifiers. Nevertheless, air purifiers with high-efficiency particulate air (HEPA) filters have been discussed as an adjunctive means for decontamination of SARS-CoV-2 aerosols in healthcare settings. Consideration of portable air purifiers with HEPA filters (HEPA purifiers) during the SARS-CoV-2 pandemic, however, should be with extensive knowledge about the functionality, efficacy and limitations of HEPA purifiers.

Discussion

Mechanisms of action

HEPA filters are usually manufactured by pleating microfiber glass or other fibrous media made with multiple layers of randomly arranged fibers with diameters ranging from 2nm to 500nm.[4] As air flows through the filter and in between the fibers, airborne particles—such as respiratory and aerosol droplets—will be trapped by one of three mechanisms: impaction, interception and diffusion, which are illustrated in Figure 1.[5] Adhesion to filter fibers may occur through Van der Waals forces, electrostatic attraction and capillary action. For particle sizes above 1μm, impaction and interception are the most significant mechanisms of filtration whereas diffusion is the dominant mechanism for trapping particles smaller than 0.1μm.[4] Particles between 0.1μm and 1μm are influenced by all three methods of capture to a lesser degree than those larger or smaller, which leads to a lower efficiency of filtration.[4]

Efficacy

To qualify as HEPA grade, filters must remove at least 99.97% of all particles that are 0.15μm - 0.2μm, for which HEPA filters are least effective. Thus HEPA filters have at least 99.97% efficiency at removing all particles, with even higher efficiencies for particles both larger and smaller than 0.15μm (Figure 2). The interesting U-shaped efficiency curve of all HEPA filters, which has a minimum at 0.15μm, is due to the relative effectiveness of the three mechanisms of particle capture at various particle sizes (Figure 2). Filters with efficiencies higher than 99.99% are also termed Ultra Low Penetration Air (ULPA) filters.

Clean air delivery rate (CADR)

HEPA purifiers of various sizes and power will remove particles at different rates. The clean air delivery rate, or CADR, is an important performance parameter created by the Association of Home Appliance Manufacturers to quantify the cubic feet per minute (CFM) of air completely filtered of a particle by the air purifier. The CADR is calculated as flow of air through the filtration system multiplied by the efficiency of filtration of the particular particle. CADR score is specific to particle sizes and typically reported for three categories of particle sizes designated as pollen (2.5μm to 80μm), dust (1μm to 30μm) and tobacco smoke (0.1μm to 1μm).[6] The CADR for dust and tobacco smoke may be most useful for determining filtration rate of aerosols and viruses respectively, which are generally in the corresponding size range.

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A previously reported study by the Environmental Protection Agency illustrates practical considerations for airborne particle decontamination by HEPA purifiers.[2] Assuming complete mixing of the air during filtration, which was found to be realistic approximation, the amount of time needed to filter a certain fraction of particles out of a volume of air was derived, using the CADR, as:

$$\mathrm{C(t)} = C_0 e^{-\left(\frac{\mathrm{CADR}}{V}\right)t}$$

where C(t) is the concentration of the particle as a function of time, C_0 is the initial particle concentration, V is the volume of the air being filtered and t is time.[2] Therefore, a HEPA purifier that has a CADR score of 300 for tobacco smoke (indicating the device removes all tobacco smoke particles from 300 cubic feet of air every minute), would be expected to clear 99% of all tobacco smoke particles in a 1000 cubic foot room (e.g., 10x10x10ft) in 15 minutes. Location of HEPA purifier placement within the room and presence of basic furniture, such as a desk and chair, did not substantially impact efficacy although pointing the purifier's air intake towards the particle source improved decontamination.[2]

HEPA filters applied to SARS-CoV-2

The vast majority of aerosols that may be produced by human cough are less than 1 micron in size[7] and the SARS-CoV-2 virion is reported to be 60nm to 140nm (0.06μm to 0.14μm) in size.[1] Although the CDC has recommended the use of HEPA filters in powered air purifying respirators (PAPRs) for effective filtration of SARS-CoV-2,[8] at present the CDC has not provided any recommendations for the use of portable HEPA purifiers for decontamination of SARS-CoV-2 in clinical areas or procedure rooms. The U.S. Food and Drug Administration (FDA) recommends that manufacturers of air purifiers intended for use related to SARS-CoV-2, evaluate effectiveness against a representative virus.[9] Coincidentally, CDC previously suggested the use of portable HEPA purifiers as an adjunctive infection control strategy for SARS-CoV-1, the causative agent of the 2003 SARS outbreak.[10]

Considerations for commercial acquisition of HEPA purifiers

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Consumers are cautioned that commercially available air purifiers make claims with labels like True HEPA, HEPA-like, HEPA-type. However, to be labeled HEPA, a filter is required to be tested and individually certified according to standards by the U.S. Institute of Environmental Sciences and Technology (IEST-RP-CC001.6) or the International Organization for Standardization (ISO 29463). Very few air purifiers meet this requirement. By comparison CADR rating is a more reliable performance parameter. Medical HEPA air purifiers may additionally claim to have an ultraviolet light or other decontaminating agent to kill microbes that deposit on the filter itself. In most cases, their microbicidal effectiveness has not been independently verified. Manufacturer guidelines should be followed for when to change filters as saturation of filters affects efficiency. Finally, proper personal protective equipment should be worn to exchange air purifier filters as these filters may contain trapped SARS-CoV-2. Proper disposal procedures should be followed to avoid contamination.

Conclusion

At present, there are no formal recommendations by the CDC for use of portable HEPA purifiers for decontamination of airborne SARS-CoV-2. Knowledge of HEPA filter functionality and prior CDC guidance for SARS-CoV-1 suggests theoretical efficacy for HEPA filters to remove airborne SARS-CoV-2, although it is important to emphasize that direct studies for SARS-CoV-2 have not been performed. Any utilization of portable HEPA purifiers for SARS-CoV-2 should be considered an adjunctive infection control measure, and be undertaken with knowledge of HEPA filter functionality and limitations in mind.

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Figure legends

Figure 1. Schematic of filtration mechanisms of impaction, interception, and diffusion. © R. Vijayakumar, reproduced with permission.

Figure 2. HEPA filter efficiency as a function of particle size and filtration mechanism. MPPS = most penetrating particle size. © R. Vijayakumar, reproduced with permission.

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Figure 1

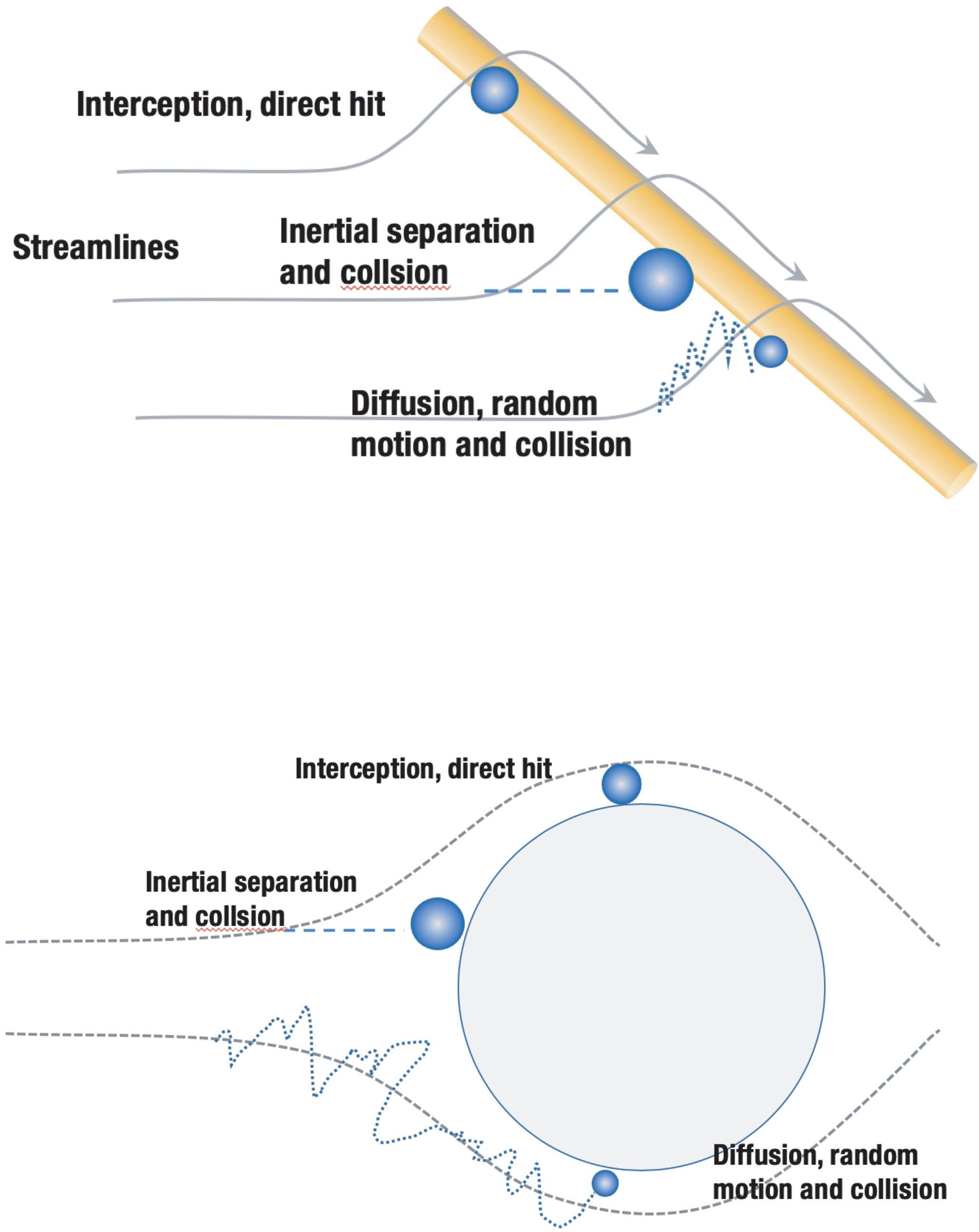

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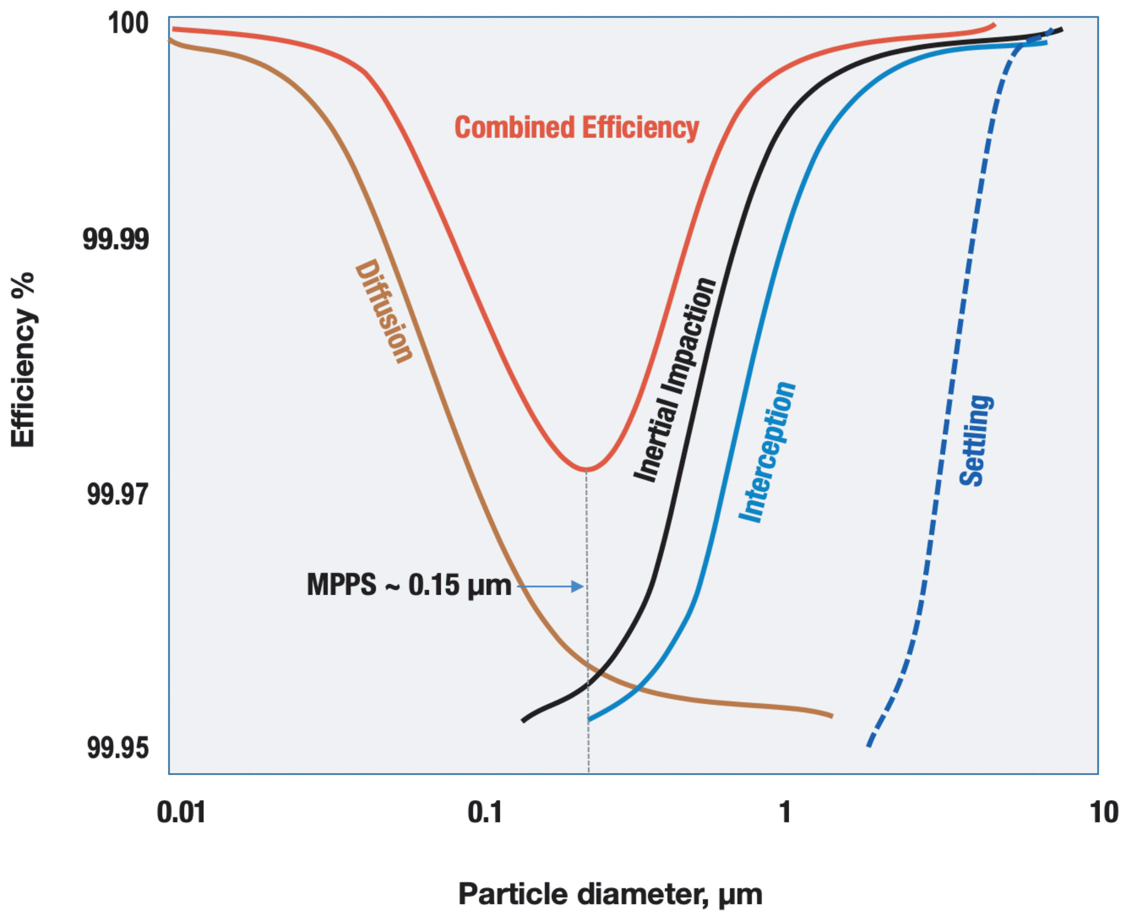
Figure 2



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