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The Effect of Mobile Indoor Air Cleaners on the Risk of Infection with SARS-CoV-2 in Surgical Examination and Treatment Rooms with Limited Ventilation Options

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Introduction

Even though the ways in which SARS-CoV-2 is transmitted are not completely understood, droplet infection from airborne particles contaminated with the virus obviously play a decisive role in human-to-human transmission [1-3]. Different forms of emission (speaking, breathing, singing, coughing, sneezing, etc.) produce a wide range of particle sizes and transmit them to the surrounding air. Breathing and speaking produce particle cells of between 0.75 μm and 1.1 μm, while coughing and sneezing produce much larger particles (larger than 5 μm) [4]. Particle distribution within a space also varies by particle size. Droplets (>50 μm) fall to the floor relatively quickly, but aerosols (<5 μm) can be detected in the air after several hours, and convection and other air movements can transport them several meters [3,5-7]. If they are inhaled, these particles can (depending on their size) penetrate deep into the respiratory tract, even reaching the alveoli [2,5,8].

These particulate matter emissions are defined by the PM_{10} unit based on the National Ambient Air Quality Standards introduced by the U.S.'s Environmental Protection Agency in 1987. The 10 here does not stand for a sharp distinction at 10 μm of aerodynamic diameter, but reflects an attempt to recreate the separation behavior in the upper respiratory tract: All particles with an aerodynamic diameter of less than 1 μm are considered, while a certain percentage of larger particles are included. That percentage falls as particle size increases until 0% is reached at 15 μm. This is ultimately where the PM_{10} designation comes from: 10 μm is the exact halfway point in the size of particles considered. In 1997, $PM_{2.5}$ was added to the guidelines. It refers to respirable (alveolar) particulate matter. The definition is analogous to PM_{10}, but the weighting function is significantly steeper (100% weighting <0.5 μm; 0% weighting >3.5 μm; 50% weighting at about 2.5 μm) [9]. The regulations were further expanded to include PM_1, which is analogous to $PM_{2.5}$, but for 1 μm.

Given the transmission methods mentioned above, precautionary measures have been taken (or mandated) throughout Germany with the goal of reducing the risk of transmitting SARS-CoV-2 by reducing aerosol and droplet exposure. It is especially important to increase air circulation in closed rooms and buildings by airing them regularly (Germany's "AHA+L" rule) [10]. This measure for potentially reducing viral load tied to airborne particles can scarcely be implemented in rooms with no windows (or at least not without major structural and technical interventions in ventilation systems).

In a previous trial, we had already noticed the positive effect of an indoor air cleaner on the concentration of airborne particles/aerosols in the ambient air of a consultation room without ventilation options [11], so we set up a repeat experiment under the same conditions but with improved, high-quality measurement technology and a mobile air cleaner with higher filtration capacity (see Material and Methods). The question here was the level of air replacement a device would need to achieve a relevant aerosol reduction and how the decline in air particles (half-life) is related to the device power level and the "personnel load" (public traffic during consultation hours).

Material and Methods

In Examination Room 2.148 (floor space of 21 m², room volume of 52 m³) of the Clinic for Orthopedics, Trauma and Spinal Surgery in Aalen's Ostalb Hospital (Picture 1), an ambient air filter device (DEMA-air tech, Stuttgart, Germany, Type AP-90) was deployed during routine surgical out-patients-clinic hours on 11/30/2020. According to manufacturer information, the device's maximum filter capacity is 720 m³/h. In addition to an activated carbon filter, a Class

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Picture 1: Surgical examination room in the out-patients clinic of the Ostalb-Klinikum Aalen without windows. *position of the Dust Monitoring system; #position of the mobile air cleaner

H13 HEPA (high-efficiency particulate air) filter was installed (European Standard 1822, minimum filter efficiency 0.3 μg/m³/h, efficiency 99.95%). The filtered air is also treated with plasma and UV light, which the manufacturer says will kill 99% of viruses and bacteria (Guangdong Detection Centre of Microbiology, Report No. 2020SP8365R03E) after the filter, has eliminated airborne particles.

During consultation hours, ambient air aerosol and airborne particle load was continuously recorded for a total of four hours with the Fidas Frog® Fine Dust Monitoring System (Palas GmbH, Karlsruhe, Germany). It continuously recorded particulate matter according to $PM_{1.0}$, $PM_{2.5}$, PM_4, PM_{10} and the total particle load (PM_{tot}) (all measurements in μg/m³). For the first two hours of consultation, the ambient air filter was switched off and the basic aerosol load in the room was merely recorded. After 120 minutes, the ambient air filter was run for seven minutes at top speed (blower at 4 of 4). The device was then operated for three more minutes at Level 3, then continuously for the rest of the consultation hours at Level 2.

For the entire period, the number of people in the room (doctor, receptionist, patients) and their length of stay were documented to the minute. Statistical evaluation was performed in Excel (Microsoft®, Version 2020).

Results

In the observation period of four hours, 43 individual personal contacts took place in the consultation room on 11/30/2020 (total duration 240 min, multiple contacts may be named when individuals occupied the room at the same time). Consultation hours began at 7:30 AM, and the ambient air filter was started two hours later.

Table 1 shows the average particulate matter/airborne particle concentration for the various measurement parameters (PM_1, $PM_{2.5}$, PM_4, PM_{10}, and PM_{tot}) in the two hours before and after the ambient air filter was switched on. A clear reduction of the average value and median was observed for all particle sizes after the ambient air filter was started each by more than 60% at least.

A 50% reduction (half-life) in the PM_1 particulate matter concentration was achieved with the seven minutes of full device power (Figure 1), even though there were relatively many people (3-4) in the room at that time (Figure 2). In the following three-minute phase at Level 3, aerosols continued to decline. Reducing filter power to Level 2 achieved a dynamic equilibrium, so that the aerosol concentration remained at the low level achieved, despite the fact that consultations continued normally.

Table 1: Average, standard deviation and median of measurement parameters (particulate matter in μg/m³) with/without mobile air cleaner filtering and reduction of average in %.

	$PM_{1.0}$	$PM_{2.5}$	PM_4	PM_{10}	PM_{tot}
Average	3.67	5.33	7.06	26.86	41.59
Standard deviation	0.23	1.1	1.99	11.25	32.45
Median WITHOUT filter	3.7	5.09	6.72	13.52	42.11
Average	1.41	1.83	2.12	5.28	11.41
Standard deviation	0.65	1.01	1.65	7.32	20.6
Median WITH filter	1.52	2.61	2.9	6.16	7.37
reduction of average with *vs.* without filter	61.5%	65.6%	69.9%	80.3%	72.5%

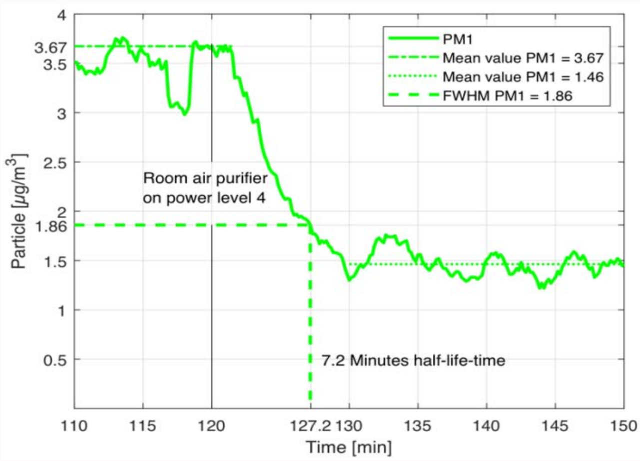

Figure 1: Aerosol concentration (PM_1) from minute 110 to 150. Minute 120 marks the start of the air filter system at Full power. Half-time reduction was achieved after 7.2 min.

Discussion

In the absence of causal therapy for COVID-19 and of a widely available SARS-CoV-2 vaccine, avoiding or reducing aerosol exposure is currently the most important measure for preventing infection. This reduction is achieved primarily by reducing contacts, social distancing, and especially by wearing masks that effectively cover the mouth and nose [12-14].

With respect to air exchange, previous studies have shown that closed rooms with public traffic and poor ventilation have much higher SARS-CoV-2 infection risk [15]. Kähler et al. [16] used an experimental setup under laboratory conditions (without public traffic) to show that mobile ambient air filters can reduce aerosol load to a minimal level within a very short period. Lelieveld et al. [17]

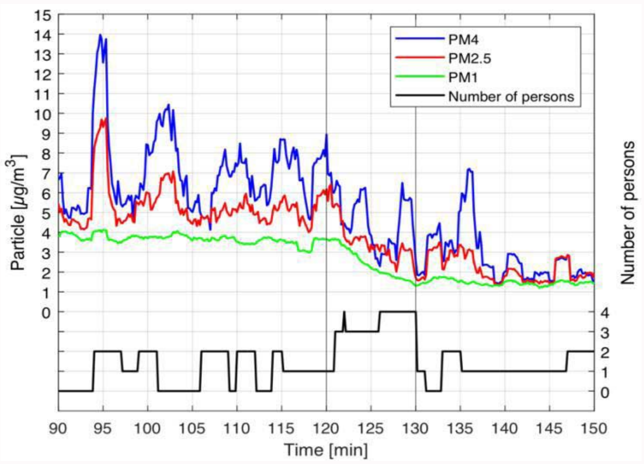

Figure 2: Particulate matter (PM_1, $PM_{2.5}$, PM_4) in μg/m³ before filtering (90 min to 120 min), during high-Speed filtering (Level 4+3; 120 min to 130 min) and under low level filtering (Level 2; 130 min to 150 min) in the out-patients clinic. Scale on the right: number of persons in the room.

used a mathematical calculation to show a reduction in SARS-CoV-2 infection risk by a factor of 7-8 with "high-efficiency HEPA filtering".

In another experimental study (classroom simulation), Bluyssen et al. [18] showed that mobile ambient air filters with a HEPA function could achieve even better air exchange than various classical room-airing scenarios.

In a previous study, we showed that mobile ambient air filters can clearly reduce aerosol load during routine surgical consultation hour operations [11]. However, this investigation's meaningfulness was lessened because of the reduced performance of the measuring instrument used. Additionally, the tested mobile air cleaner was of less filter capacity and was just run on automatic level during the whole measurement. The new investigation featured continuous, high-quality data recording that allowed a comprehensive picture to be captured. The half-life for the aerosol load reduction was just seven minutes at full device power, even though several people were in the room at the same time during that period (Figure 1, 2). When consultation hours were continued and the device was set to a lower speed (because of the noise generated at top speed), the reduction in aerosol concentration achieved could be maintained indefinitely.

The continuous recording of dimension parameters and the documentation of the persons present in the room allowed the effect of persons in the room to be established. In the phase before the ambient air filter was switched on, there is an especially pronounced relationship between the number of persons in the room and the peaks in each size of aerosol particle. The more people were in the room, the higher the number of aerosols measured (Figure 3). This observation is limited by the fact that no exact mathematical relationship could be established. This is easily explained by the fact that while the presence of a person in the room was documented, the specific aerosol emissions by a given individual is dependent on a number of factors (type and duration of speech; coughing; sneezing; movement in the room; etc.), so that these emissions can never be standardized or predicted.

In our setup, the ambient air filter was turned down a level after seven minutes at top speed and down another level after three more minutes. This was due to the noise generated by the device. At full power, the device was simply too loud to continue consultation comfortably. Bluyssen et al. [18] noted a similar effect. Our results show that after an initial cleaning of the room's air, the number of aerosols can be kept constant at the level achieved even when the ambient air filter's fan speed is turned down to a level where the noise it produces is absolutely acceptable. This is a decisive point for future device regulation and control. In the brief periods between meetings with patients during which no one is in the room, an ambient air filter should be run at full power to simulate intensive ventilation.

Given a maximum device filter capacity of 720 m³/h at full power and a room volume of 52 m³, the air in a room can be completely replaced six times in one hour. This would fulfill German official's regulatories for indoor air ventilation [11], and means that 7.5 half-lives could theoretically be achieved. Assuming first-order elimination (elimination speed falls with aerosol concentration); the original concentration would be reduced by 87.5% after three half-lives and by more than 99% after seven. Because the manufacturers of the ambient air filter claim that more than 99.9% of viruses and bacteria are eliminated with UV light and plasma, the risk of aerosol transmission of pathogens (SARS-CoV-2) in the examination room described above would thus be practically eliminated [19].

Conclusion

A mobile ambient air filter can significantly reduce the aerosol load in a closed room without ventilation capability under real-world conditions as represented by surgical consultation hours. This results in a corresponding infection risk potential reduction for a disease, such as SARS-CoV-2, that is transmitted by aerosols. In hospital examination and conference rooms whose design provides no ventilation capability, using mobile ambient air filters is absolutely advantageous given the current conditions of the COVID-19 pandemic.

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