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Fundamental protective mechanisms of face masks against droplet infections

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A B S T R A C T

Many governments have instructed the population to wear simple mouth-and-nose covers or surgical face masks to protect themselves from droplet infection with the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) in public. However, the basic protection mechanisms and benefits of these masks remain controversial. Therefore, the aim of this work is to show from a fluid physics point of view under which circumstances these masks can protect against droplet infection. First of all, we show that the masks protect people in the surrounding area quite well, since the flow resistance of the face masks effectively prevents the spread of exhaled air, e.g. when breathing, speaking, singing, coughing and sneezing. Secondly, we provide visual evidence that typical household materials used by the population to make masks do not provide highly efficient protection against respirable particles and droplets with a diameter of 0.3–2 μm as they pass through the materials largely unfiltered. According to our tests, only vacuum cleaner bags with fine dust filters show a comparable or even better filtering effect than commercial particle filtering FFP2/N95/KN95 half masks. Thirdly, we show that even simple mouth-and-nose covers made of good filter material cannot reliably protect against droplet infection in contaminated ambient air, since most of the air flows through gaps at the edge of the masks. Only a close-fitting, particle-filtering respirator offers good self-protection against droplet infection. Nevertheless, wearing simple homemade or surgical face masks in public is highly recommended if no particle filtrating respiratory mask is available. Firstly, because they protect against habitual contact of the face with the hands and thus serve as self-protection against contact infection. Secondly, because the flow resistance of the masks ensures that the air remains close to the head when breathing, speaking, singing, coughing and sneezing, thus protecting other people if they have sufficient distance from each other. However, if the distance rules cannot be observed and the risk of inhalation-based infection becomes high because many people in the vicinity are infectious and the air exchange rate is small, improved filtration efficiency masks are needed, to take full advantage of the three fundamental protective mechanisms these masks provide.

1. Introduction

At present, humanity is threatened by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic. The risk of severe infection with the virus depends heavily on physical factors of the infected persons and the quality of the medical system. According to a recent study the estimated infection fatality ratio (IFR), averaged over all age-groups including those who don't have symptoms, is between 0.2% and 1.6% with an average of 0.66% (Verity et al., 2020). These numbers look small, and the fatality risk may seem acceptable, and therefore the danger is often marginalized. This is surprising considering that the Apollo crew, the space shuttle astronauts and the Allied soldiers during the 2003 Iraq war took a deadly risk of this magnitude. Only very few people take such risks voluntarily and with full consciousness. For comparison, the lethal risk of a fatal accident with a commercial aircraft was 1:7700000 in 2008 and even such a small risk is not taken by some people. Considering that the IFR of the seasonal flu is about 0.04–0.1% (Centers for Disease, 2010) or even much lower (Wong et al., 2013) the mortality rate of SARS-CoV-2 appears to be significantly higher than for influenza flu. Although the numbers for SARS-CoV-2 are quite preliminary and the estimates may drop

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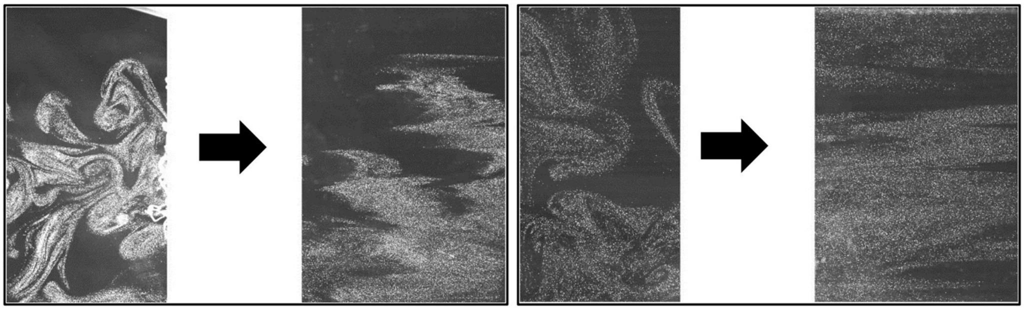

Fig. 3. Effectiveness of particle filtering with the filter material of a surgical face masks (left) and a hygienic mask (right). The arrow indicates the flow direction and filter position. The second video in the supplementary material shows the animated sequences.

range. Only very large droplets are retained by these materials and therefore these materials are suitable for their intended use, but not as filter material for small droplets. It is therefore strongly discouraged to make masks from these materials with the aim of protecting oneself from infection.

Furthermore, a very strong fleece was tested, which serves as a protective coating on ironing boards. The material is 4 mm thick, completely opaque and has a pressure drop of about 35 Pa. However, a filter effect is not visible, as indicated in Fig. 5 (left). The droplet clouds flow almost unfiltered through the fleece. Even several layers of a dense fabric do not have a proper filtering effect on the considered droplet sizes, which escape mainly when breathing, speaking, singing and coughing.

Good results could only be achieved with the material of a vacuum cleaner bag with fine dust filter properties, see Fig. 5 (right). Despite the small droplets used in these tests, almost all droplets are reliably filtered out. Consequently, also no larger droplets will be able to pass through the material. According to the manufacturer SWIRL, the material filters 99.9% of fine dust down to 0.3 µm diameter. This vacuum cleaner bag with fine dust filter therefore has better filtering properties than all tested materials and masks and even an FFP2 protective mask has poorer filtering properties, as it only has to filter out 94% of the fine dust down to 0.6 µm to meet the specifications (Uvex, 2020). The material of vacuum cleaner bags with fine dust protection is therefore very well suited as a self-protecting mask if only the filter effect is considered. However, because vacuum cleaner bags are not certified clinical products, they may contain unhealthy ingredients that kill bacteria and harmful fibers that may leak from the bag material. It is therefore uncertain whether this material is suitable in practice as a material for a respirator mask.

Fig. 6 (left) illustrates the filtering capabilities of an FFP3 mask under the test conditions. Nearly all droplets are filtered out as

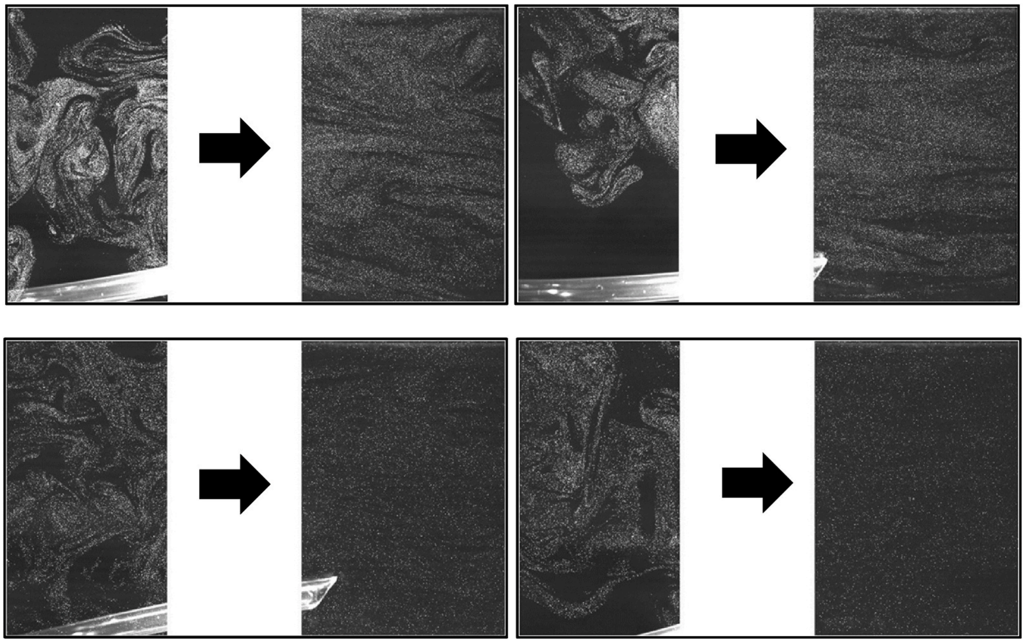

Fig. 4. Effectiveness of particle filtration. Toilet paper (upper left), paper towel (upper right), coffee filter (lower left), microfibre cloth (lower right). The second video in the supplementary material shows the animated sequences.