Quantifying the impact of masks on exposure to infection by SARS-CoV-2

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Abstract

Since the influenza outbreak of 1918 there has been a need to model the probability of infection of airborne contagions. Sadly, today the world faces a new pandemic known as COVID-19 and we are still in need of an efficient prediction model. In our study, we quantify the probability of SARS-CoV-2 transmission by applying a new model for predicting the risk of a healthy person getting sick when in the presence of an infected individual. The study uses quadrature-based aerosol modeling, which tracks the dispersion and evolution of respiratory aerosol particles. The model predicts number or concentration of particles and virons downwind of an infected individual, the deposition into the nasal cavity of a healthy individual, and the subsequent risk of infection. Our main objective was to elucidate the mask filtration and deposition components of this model.

Motivation

According to the World Health Organization, as of December 7th, 2020 there has been over 66 million confirmed cases of COVID-19 in 220 countries. There also has been more than 1.5 million deaths worldwide. These numbers demonstrate the vital need to understand the probability of infection when exposed to a carrier of SARS-CoV-2.

**Please note that the following figures each represent a single scenario with a single set of assumptions.*

Thematics

- Aerosol creation
- **Mask filtration efficiency**
- Jet plume
- Evaporation
- Room dynamics
- **Particle deposition**
- Viral load

Bold bullet points indicate areas of research focus

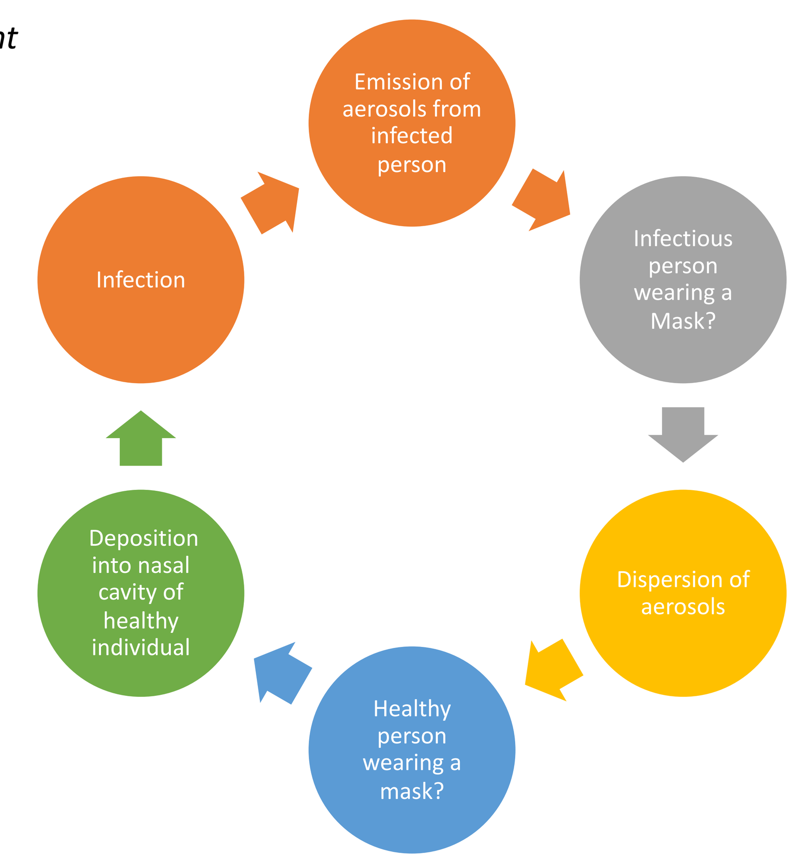

Figure 1. Overview of the infection process of airborne SARS-CoV-2. The question marks indicate that a mask may or may not be present at this stage in the cycle.

Methods of Mask Filtration Efficiency

Mask filtration efficiencies were calculated from data that was accumulated from sources that performed filtration efficiency (FE) research, such as Asadi et al. 2020 (1) who collected data on outward particle emissions during talking, breathing, and coughing, as well as Marr et al. 2020 (2) whose inhalation data was incorporated into our work, and Konda et al. 2020 (3) whose data was included on proper fit of surgical masks.

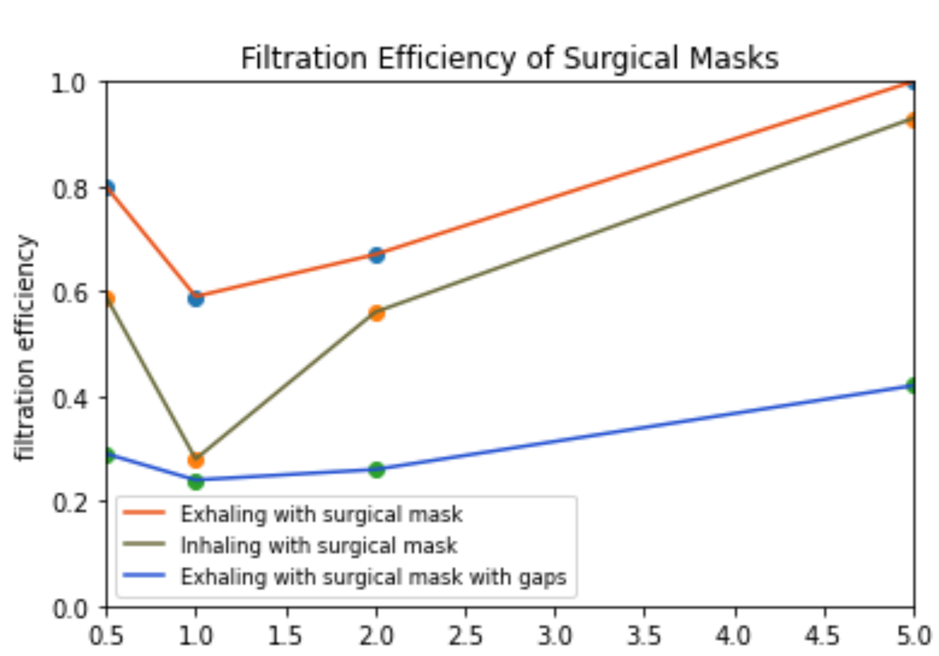

Figure 2. Averages of filtration efficiency at particle aerodynamic diameters of 0.5, 1.0, 2.0, and 5.0 micrometers

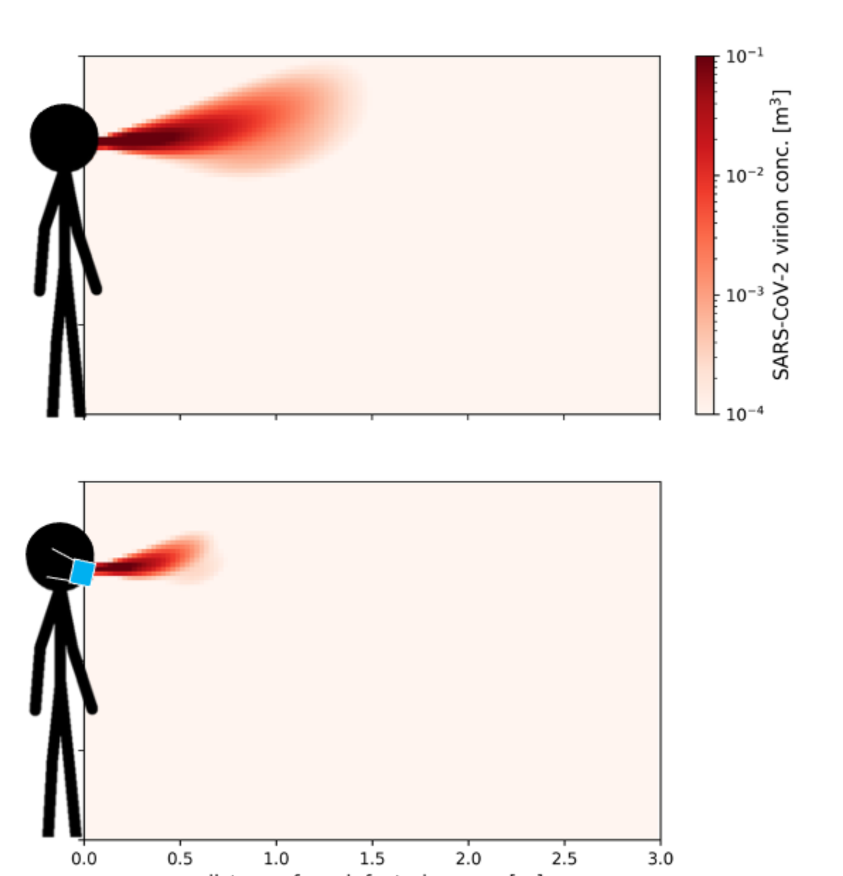

Figure 3. Probability of reach of SARS-CoV-2 virions concentration. The upper graph demonstrates an infected person exhaling and the lower graph demonstrates the same infected individual exhaling with the use of a surgical mask.

Methods of Deposition Modeling

- In Silico methods have been implemented by use of Python code with Anaconda Navigators Spyder Application.
- The deposition model is coded using the model put forth by Y.S. Cheng (4). Which takes into consideration the diffusion and impaction parameters related to aerodynamic particle size, in addition to introducing nasal and oral breathing equations that give a total deposition efficiency.

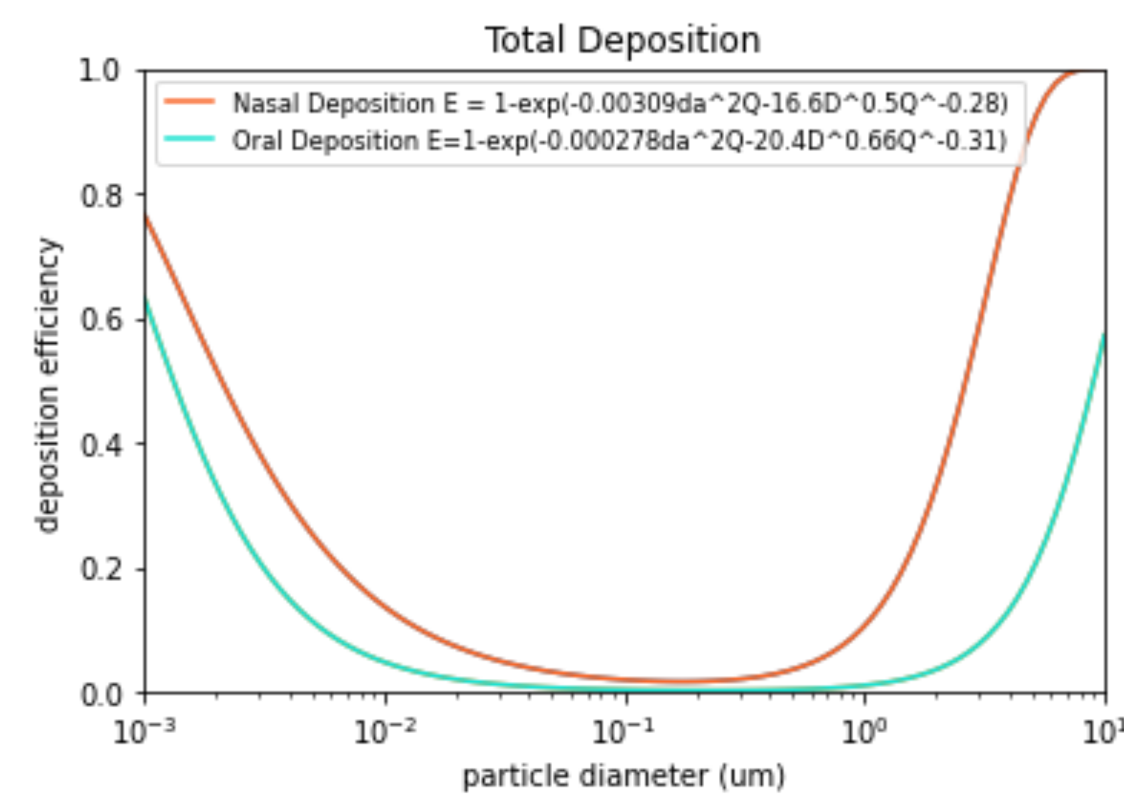

Figure 4. Deposition efficiency as a function of particle diameter (4). This graph was used to benchmark our model against the Cheng model .

Putting it all Together

Works collected and produced by Dr. Fierce and her team members will be encompassed into one code that will be able to output the likelihood of infection based on many parameters including but not limited to

- Emission of respiratory particles
- distance from infected source
- Near field particle dispersion
- Plume rise due to buoyancy
- Evaporation
- Settling due to gravity and diffusion
- Removal due to air exchange
- Deposition into nasal cavity
- Probability of infection based on number of virions depositing
- Mask filtration efficiency

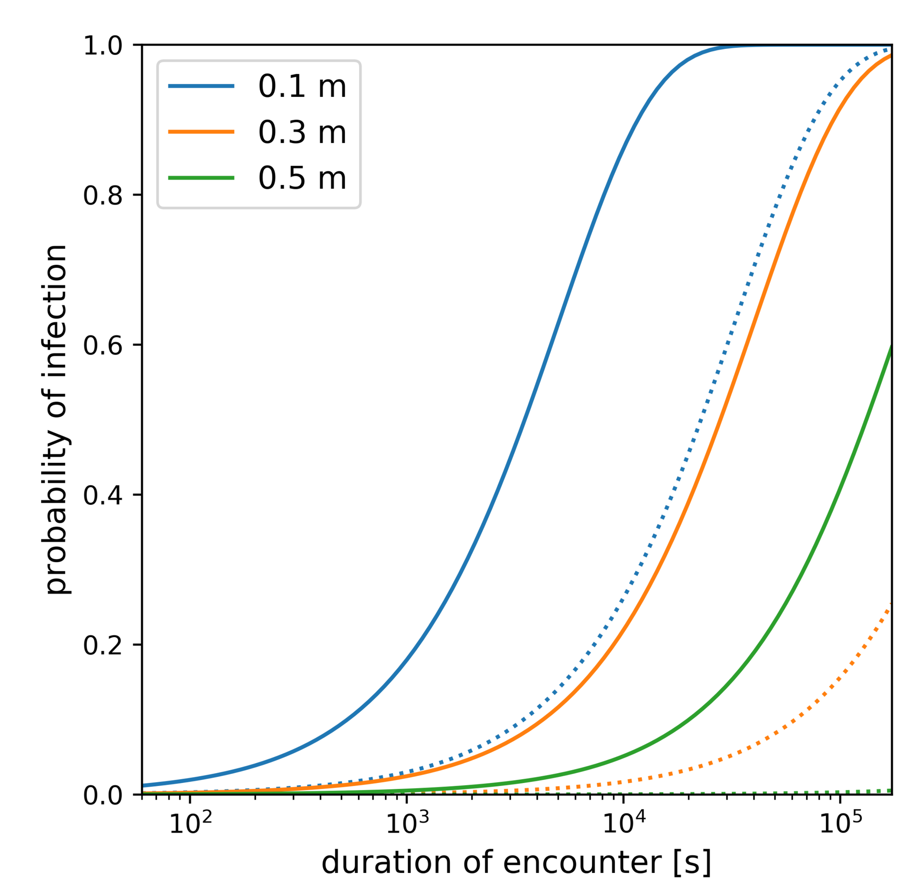

Figure 5. Probability of infection as a function of time that a person is exposed to infectious particles. The solid lines indicate that no mask is present while at distance 0.1, 0.3 and 0.5 meters from infected individual. Dashed lines indicate a well-fitted surgical mask is being worn by both the susceptible and contagious person.

Figure 6. Predicted rate of deposition on the nasal epithelium (which we believe to be the infection site) at a certain distance from and infected individual.

Significance

This in silico model can be used to predict the transmission of SARS-CoV-2 to a healthy person when in the presence of an infected individual. The model may also help to understand the appropriate distance to maintain while social distancing, as well as influence other precautions to be taken by the public. This work may also be used to predict the spread of other infectious airborne diseases that may emerge in the future.

Future Work

Further studies including combining epidemiological models as well as the impact of ventilation should be considered.

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