Title: Face mask fit modifications that improve source control performance

Methods

1. Source Control Measurement System

The source control measurement system was used to measure the collection efficiencies (% particles blocked) for coughed or exhaled aerosols by fit modified or unmodified face masks (Figure 1). A test aerosol solution consisting of 14% potassium chloride (KCl) and 0.4% sodium fluorescein was propelled through the mouth of an elastomeric headform outfitted with a face mask (with or without fit modification) during simulated coughs (4.2 L volume) and breathing (15 L/min) into a 136 L collection chamber. Three to six independent experimental replicates were performed, each examining a new face mask and fit modification under the set experimental conditions. The test aerosol collected from control experiments without a mask had a total mass of 525 μg (cough) and 495 μg (exhalation). An Anderson Impactor operating at 28.3 L/min was used to collect the aerosolized particles into seven size fractions by their aerodynamic diameter: <0.6 μm; 0.6-1.1 μm; 1.1-2.1 μm; 2.1-3.3 μm; 3.3-4.7 μm, 4.7-7.0 μm; and >7 μm. After aerosol collection was completed, the impactor plates were rinsed with 0.1 M Tris solution and the fluorescence of the solution was measured using a fluorometer (SpectraMax M4, Molecular Devices). Because of possible losses from settling, particle data for the >7 μm size fraction (<0.7% of the total test aerosol mass) was not included in the collection analysis.

2. Simulated Exposure System

The testing environment consisted of an environment chamber measuring 3.15 m x 3.15 m x 2.26 m (gross internal volume of 23.8 m^3, Figure 2). An internal re-circulating HEPA filtration system (FS4010, Flow Sciences, Leland, NC) was used to reduce background aerosol/particle concentrations to near-zero prior to each experiment. The HEPA system consisted of a 10.8 cm inlet duct position along the left wall 55.9 cm from the ground leading to the central motor/filter unit and an outlet duct positioned along the right wall at a height of 2.19 m from the ground; no external fresh air was introduced into the environmental chamber during experimentation. Six Grimm 1.108 optical particle counters (OPCs; GRIMM Aerosol Technik Ainring GmbH & Co. KG; Ainring, Germany) were positioned at height of 152 cm throughout the chamber. The OPCs measured particle concentrations in channels ranging from 0.3 to 3.0 μm at a frequency of 1 Hz, except for one older OPC sampler at 0.167 Hz. Four OPCs were affixed to telescopic stands 152 cm above the floor and referred to “area samplers”. One OPC was positioned 3.2 cm to the left of the mouth central axis and anteriorly planar to the mouth opening of the recipient simulator (see below) and fit behind a mask affixed to the simulator; this position is denoted as “at the mouth of the breather” for presentation purposes. The remaining OPC was positioned 8.9 cm to the right of the mouth central axis and anteriorly planar to the mouth opening of the recipient simulator to allow for measurement in the personal breathing zone outside of a mask affixed to the simulator. All OPCs were controlled and data logged using a custom program in LabVIEW v. 2009 (National Instruments; Austin, TX).

To simulate source aerosol exposure to a recipient, a breathing simulator (Warwick Technologies Ltd., Warwick, UK) with a pliable skin head form (Respirator Testing Head Form 1 – Static, Crawley Creatures Ltd, Buckingham, UK) was placed upon a mobile cart to enable alteration of the distance between source and the recipient. The test aerosol was a 14% w/v KCl solution nebulized by a single jet Collison atomizer (BGI, Butler, NJ) with an inlet pressure of 103 kPa (15 lbs./in^2) prior to passive drying (TSI Diffusion Dryer, 3062), dilution with dry filtered air at 15 l/min (exhalation), and

neutralization by an ionizer (Model HPX-1, Electrostatics, Inc.). The mouth of the recipient simulator head form was positioned 152 cm above the floor. The simulator breathed with a sinusoidal waveform at 21.5 breaths/min with a ventilation rate of 27 l/minute. These parameters are approximately the average of the ISO standards for males and females performing moderate work. Both simulators were controlled during all experiments using custom scripted programs in LabVIEW.

3. Experimental Procedure

For simulation studies with masking conditions, a medical or cloth face mask (fit modified or unmodified) was placed on the respective simulator followed by fit assessment using the PortaCount Pro+ (Model 8036, TSI) in the N99 mode (all particles sized between 0.02 and 1 μm diameter) as per manufacturer's instructions. Briefly, the FitPro+ Test software was initialized on the PortaCount Pro+, protocol OSHA 29CFR1910.134 was selected, mask type and size were entered. Following a series of breathing exercises, a quantitative mask fit value was reported by the PortaCount Pro+ system. A daily quality assurance test was conducted using the 3M 1860 N95 respirator. The test aerosol was then generated and propelled with either a simulated cough or exhalation through the headform.

a. The total aerosol mass (μg) was used to measure the collection efficiency of face masks (with and without fit modification) and were compared with no mask controls using the source control measurement system.

b. For exposure simulations, the mean mass aerosol concentration ($\mu g/m^3$) at the mouth of the unmasked recipient when no mask was worn by the source simulator was compared when a fit modified medical or cloth mask was worn.

4. Data Processing and Statistical Analysis

a. Mask source control performance was assessed by calculating the collection efficiency which is defined as ($= 1 - M_{mask}/M_{control}$) where M_{mask} = total mass of the aerosol particles that passed through or around the fit modified source control device and was collected by the impactor and $M_{control}$ = total mass of the aerosol particles expelled by the source control measurement system without a face mask and collected by the impactor.

b. For exposure simulation studies, the background aerosol concentration was determined based on the mean particle concentration during the three minutes prior to exhalation. The bin-specific particle counts per cubic meter of air was converted to volume based on the mean bin diameter (assuming spherical particles) and then to mass concentration by multiplying by 1.984 g/cm^3 (density of KCl). The total mass concentration was calculated by summing the bin-specific mass concentrations for all size bins. The mean mass concentration was calculated as the average mass concentration over the test duration and served as the exposure metric in these simulations.

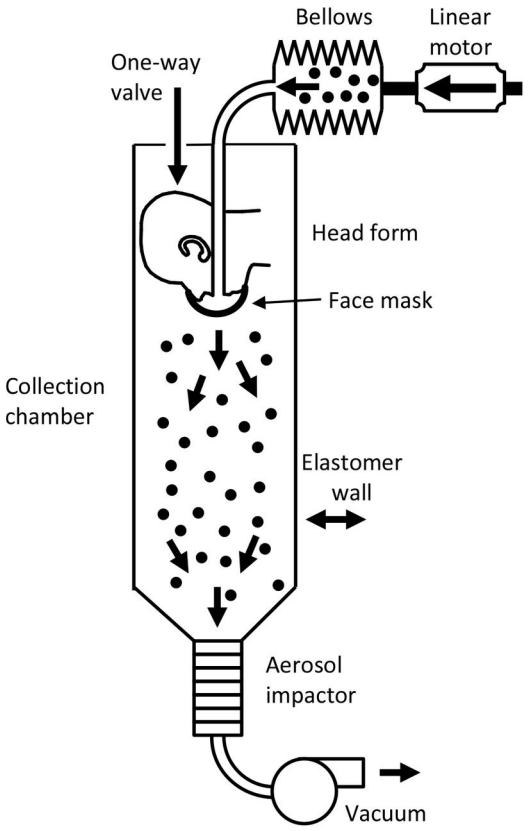

Figure 1. Schematic of source control measurement system looking at mask blocking efficacy.

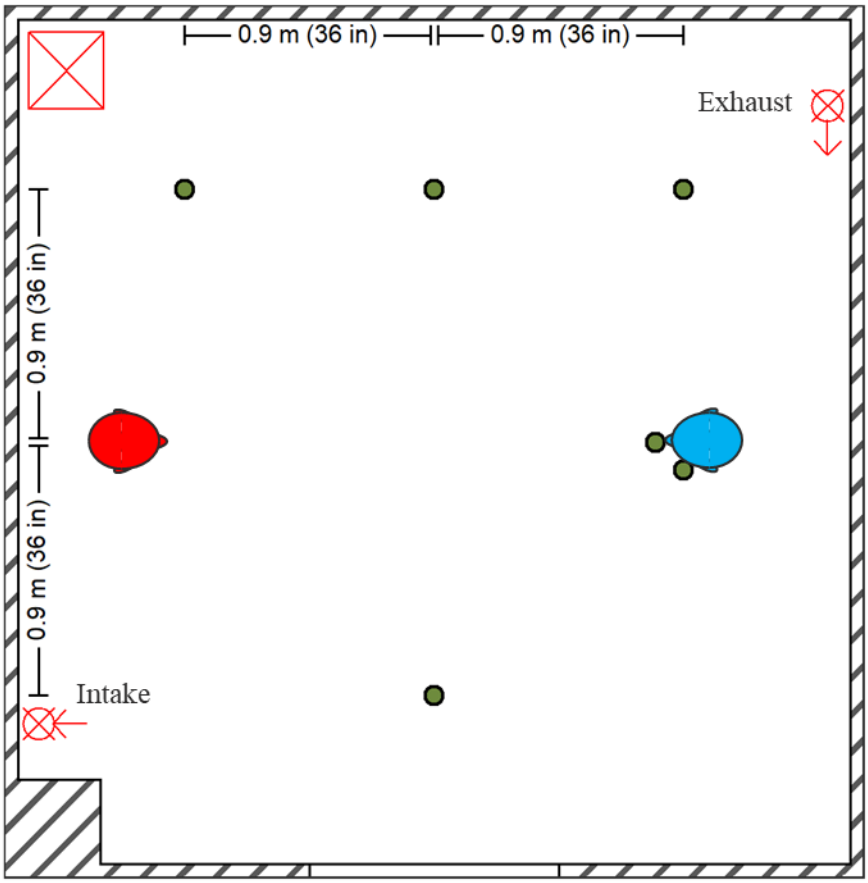

Figure 2. Schematic of environment chamber and respiratory simulators used in aerosol exposure masking studies.