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Preliminary Findings of Control of Dispersion of Aerosols and Droplets during High Velocity Nasal Insufflation Therapy Using a Simple Surgical Mask: Implications for High Flow Nasal Cannula

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Conflict of Interest:

Charles W. Atwood has received fees from Vapotherm, Inc for clinical research consultation. Jessica S. Whittle has received fees for clinical research consultation and speaker honorarium from Vapotherm Inc. Scott Leonard, Ronald J. DeBellis and George C. Dungan are employees of Vapotherm Inc. Brian K. Walsh and Wayne Strasser declare no conflict of interest.

COVID-19 Pneumonia presents with severe hypoxemic respiratory failure, caused by the SARS-CoV-2 virus. The primary mode of transmission appears to be droplet-borne. Respiratory support and high levels of oxygen are required in the acute management of these patients. High Flow Therapies have been included as part of the possible management of COVID-19.[1,2] One such modality is High Flow Therapy, including High Velocity Nasal Insufflation (HVNI), High Flow Oxygen (HFO), and High Flow Nasal Cannula (HFNC). HVNI shares characteristics with HFNC/HFNO, in that all reliably deliver high flows of oxygen enriched gas at high FiO_2 to the patient via an open nasal interface. High Flow Therapy has demonstrated ability to help manage Hypoxic or Type I Respiratory Failure.[3,4] All High Flow therapies also share the same issue of potential aerosol generation.

A recent correspondence raised questions about healthcare worker safety during use of Non-invasive Ventilation (NIV) and HFNC therapies.[5] HFNC has been studied and found to have limited particle dispersion when properly fitted.[6] A recent recommendation has advised the use of a surgical mask over the face of a patient whilst wearing the High Flow therapy to help reduce inadvertent aerosol.[7] This is the initial report of a study using computational fluid dynamic (CFD) simulation on the ability of a mask to reduce the velocity of exhaled gas flow and capture particles during HVNI.

Methods

The study used CFD modeling to evaluate: 1) effect of the addition of a surgical mask over the face on the velocity of the gas outflow into the room, 2) what is the consequence of leakage around the mask, 3) what effect does the addition of a mask have on the ability of HVNI to flush the upper airway deadspace. Two models were used to answer these questions.

For velocity and leak analysis an *in-silico* simulation (ANSYS, Inc., Canonsburg, PA, USA) modeled a 3D head placed on a virtual bed positioned 736mm above the floor of a virtual $43m^3$ room (4.87m x 3.65m x 2.44m), which included simulated inlet and outlet vents (2 each, 0.305m x 0.305m) for modeling air handling in the room (6 air exchanges per hour). A Type-I surgical mask surgical mask was modeled over the face. Gaps in the mask/face interface were included to model the effect of poor-fit on a patient: 8 gaps totaling $679mm^2$ cross-section were modeled for all experiments (including a gap on both sides of the nose, simulating poor mask fit at the nose). This included 6 gaps and 2 inlets for HVNI cannula tubing. The mask was modeled to match EN14683 standards. HVNI therapy was modeled from CT-derived architecture of a petite adult female, sinusoidal breathing a 500ml tidal volume at 32 breaths per minute and a 1:1 Inspiratory/expiratory ratio (the exaggerated tidal volume was intentional to model ‘worst-case’ expiratory flow and velocity). HVNI flow was modeled at 40 LPM through a model of Vapotherm Adult Small/Pediatric cannula. Low Flow Oxygen delivery was modeled using a similar cannula delivering 6 $L{\cdot}min^{-1}$ continuous flow (LFO_2). A third scenario of ‘No-Therapy’ on a patient breathing with the same dynamics was modeled for comparison.

A tetrahedral mesh-geometry totaling 6 million elements with 1.1 million resulting polyhedra was used. Mesh density was set to achieve 4 elements through the thickness. Simulations are transient, and five hours run-time were simulated for development of flow in the room. Particles were simulated coming from the airway, ranging from 0.1-100µm. The model used a single particle generation rate across all scenarios. Particle mass disposition is reported as a proportion, as actual volume of particulate generation in patients will vary.

The second experiment was performed using a different simulation, evaluating CO_2 flush, performed using a CT-derived anatomically accurate model of a petite adult airway and face. The model assumed exhalation of 8% CO_2, HVNI delivered at 40L·min^{-1} via a Vapotherm Adult Small/Pediatric cannula. Flush was measured over a simulated complete breath (Vt=500ml), and washout was computed from the known remaining mass of CO_2 in the modeled deadspace, with and without a mask.

Results

The first simulation showed persistence of high velocities (necessary for carrying non-airborne particles) was very low for all scenarios using the facemask (Figure 1). All scenarios showed the mask receiving the bulk of the breathing outflow, entering the matrix of the mask and rapidly losing velocity through diffusion into the mask. The intentional leak points showed greater leak with HVNI than LFO_2 or No Therapy (16.5% v 12.6% v 11.6% leak respectively). Other than flow through the intended leaks, the velocity exiting the mask material was minimal. Simulated HVNI therapy through the mask does not have an exaggerated exiting velocity (with known capability of capturing and propelling droplets) and is comparable to that modeled for LFO_2 or tidal breathing.

The simulated surgical mask during HVNI at 40 L·min^{-1} captured 83.2% of particles; LFO_2 at 6 L·min^{-1} captured 73.6% of particles; and tidal breathing (No Therapy) captured 87.2% of particles. It is important to note that the proportion of droplets (i.e., ≥ 5μm) which are captured in the mask with HVNI therapy is 85.9%, as compared to 75.9% while receiving LFO_2, and 89.9% during tidal breathing. The greater HVNI capture is likely due to the rapid incorporation of high velocity particles into the mask material, as compared to the lower velocity LFO_2 therapy gas stream. The minority of particles (15.9%) which escaped the HVNI simulation showed travel length of greater than 1m as compared to 6.9% on LFO_2. This was overwhelmingly attributed to mask leak. For comparison, simulation of tidal breathing *without* a mask showed 31% of particles leaving the nose and mouth with travel greater than 1m from the face.

In the second experiment, the simulation showed a flush efficacy of 52% at 40 L·min^{-1} under the mask. This is a moderate reduction in CO_2 clearance. This is slightly lower than flush calculated from the model run at 35 L·min^{-1} without a mask (62.1% flush at same ventilatory parameters – 16% difference). A drop in flush efficiency should therefore be accounted for with increased flow if the patient exhibits increased work of breathing.

Discussion

These simulations suggest that: (a) velocity of exhaled gas flow of patients receiving LFO_2 or HVNI therapy can be substantially slowed using a surgical facemask in place –with the attendant reduction in particulate dispersal, (b) the simulated mask showed capture of the majority of particle mass, with slightly better capture than LFO_2, and leakage occurring primarily at the points of the intentional leak, and (c) a moderate reduction in flush capability occurs with a surgical mask in place, suggesting increasing flow rate if the patient is displaying increased work of breathing.

These preliminary findings suggest the addition of a simple Type-I surgical mask may provide an effective tool to further reduce droplet deposition due to exhaled gas flow, except at mask leaks. A properly fitted mask may be a reasonable tool to further manage particulate contamination of the room for patients with droplet-borne disease. Note that all scenarios (HVNI, LFO_2, tidal breathing) resulted in particulate and airflow escape, and PPE/Environmental precautions must considered while managing patients on HVNI, even using the surgical mask. Further high-definition simulations are underway to determine the geometry of deposition as well as to refine particulate dynamics.

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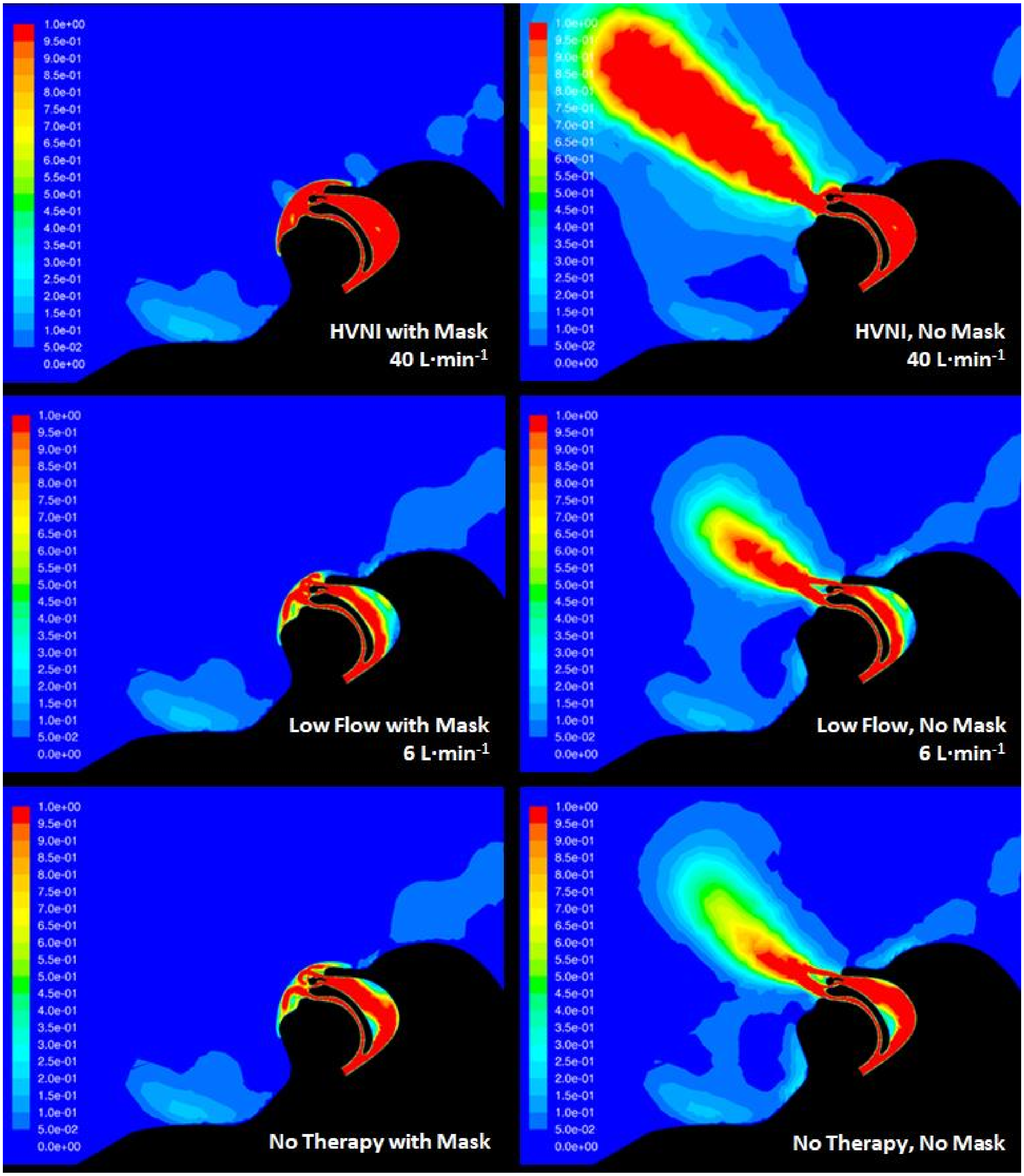
HVNI with Mask
40 L·min-1
HVNI, No Mask
40 L·min-1
Low Flow with Mask
6 L·min-1
Low Flow, No Mask
6 L·min-1
No Therapy with Mask
No Therapy, No Mask
1.0e+00
9.5e-01
9.0e-01
8.5e-01
8.0e-01
7.5e-01
7.0e-01
6.5e-01
6.0e-01
5.5e-01
5.0e-01
4.5e-01
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Abbreviation List

CFD	Computational Fluid Dynamics
HVNI	High Velocity Nasal Insufflation
HFO	High Flow Oxygen
HFNC	High Flow Nasal Cannula
NIV	Non-Invasive Ventilation
PPE	Personal Protective Equipment
WHO	World Health Organization