Aerodynamic SARS-CoV-2 transport in non-invasive ventilatory support methods: a passive tracer study

R.H.J. Hebbink [1] J. Elshof [2,3] S. Wanrooij [1] W. Lette [1] C.H. Venner [1]
M.L. Duiverman [2,3] R. Hagmeijer [1]

[1]Engineering Fluid Dynamics, University of Twente, Enschede, The Netherlands

[2]Department of Pulmonary Diseases/Home Mechanical Ventilation, University of Groningen, University Medical Center Groningen, Groningen, The Netherlands

[3]Groningen Research Institute for Asthma and COPD (GRIAC), University of Groningen, Groningen, The Netherlands

Abstract

Non-invasive ventilatory support is used in COVID-19 treatment, but little is known about associated virus transport, putting healthcare professionals at risk. This study reveals treatment-related aerodynamics by passive tracer visualisation. All therapies showed extensive jet dispersion, illustrating the risk of droplet-driven transmission that depends on jet-extension and jet-orientation. Aerosol transport is inevitable in non-filtered methods. Further research is needed to guide therapy set-up adjustments depending on actual infectious SARS-CoV-2 spread.

Introduction

In the treatment of COVID-19 various forms of non-invasive ventilatory support are used. Studies have been done on the clinical effectiveness of these therapies, but little is known about the associated virus transport. This puts healthcare professionals at risk. This study uses passive-tracer visualisation to reveal the aerodynamics during various ventilatory support methods.

Background

Exhaled air contains droplets ('micro-bullets') and aerosols ('floating particles'). Droplets are launched and driven by exhalation jets, with a reach depending on droplet size, jet-strength and jet-orientation. Aerosols, however, stay airborne and viable for hours, and can end-up anywhere.

Methods

A 3D-printed upper airway geometry, based on a CT-scan of a male adult obtained from [1] and modified with author's permission, is used as patient. Breathing is simulated by a pneumatic cylinder driven by a linear motor. Passive-tracer transport in exhaled air is visualised by generating smoke in a reservoir connected between the lung and the head. The used smoke cartridges produce particles between 0.3 and 2.5 microns. Normal breathing, NHF, CPAP, BiPAP, Venturi masks, a nebulizer and a non-rebreathing mask are tested.

Results

The images show the frontal (left) and top (right) views with the regions of concentrated smoke at the end of exhaling, approximately 2 s after the start of exhalation. The distance between two lines is approximately 10 cm on reference height.

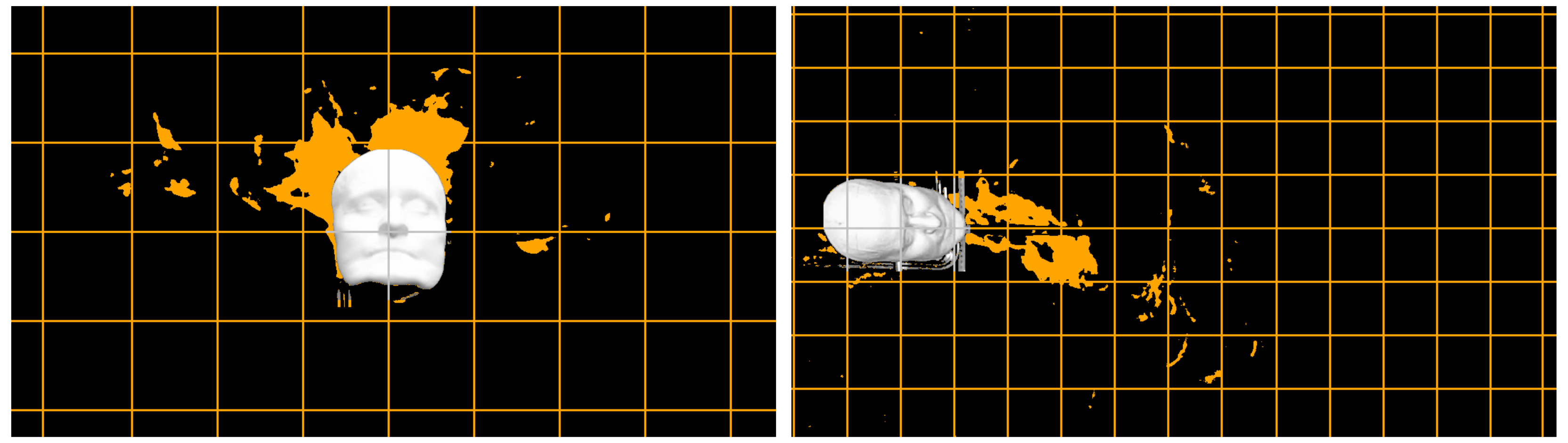

Figure: Normal breathing

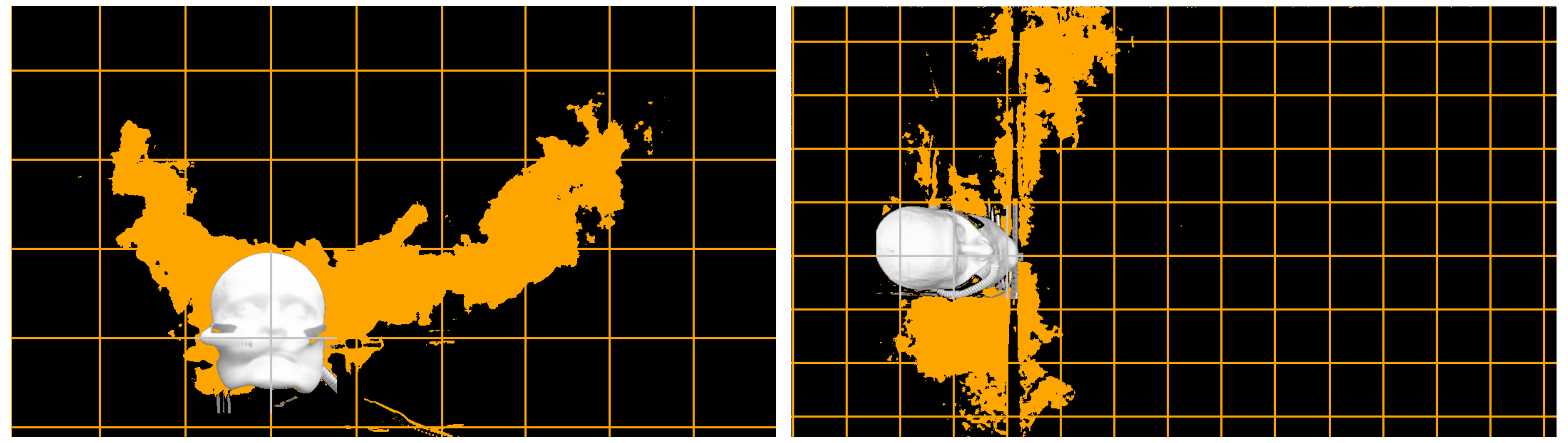

Figure: Nasal High-Flow Therapy, medium cannula, 30 L/min

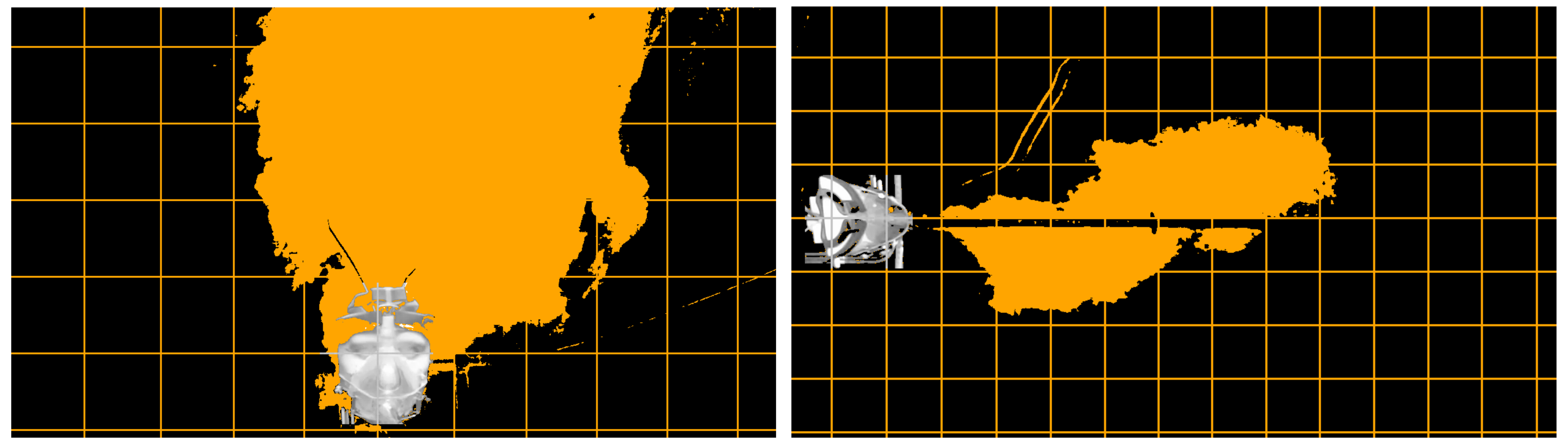

Figure: BiPAP, vented mask, 10/5 cmH_2O

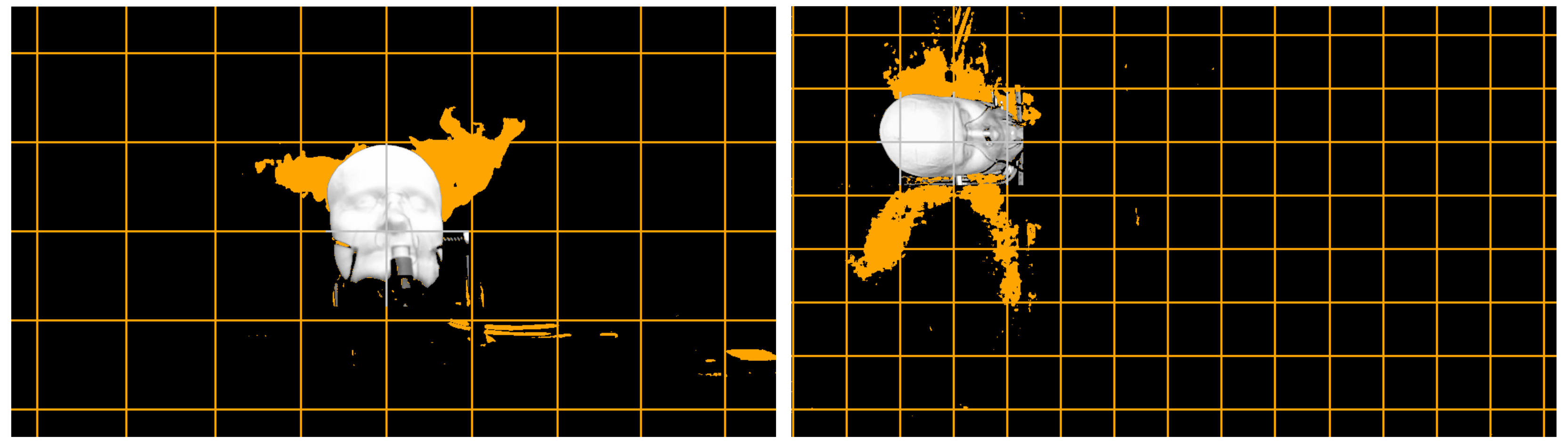

Figure: Venturi mask 60%

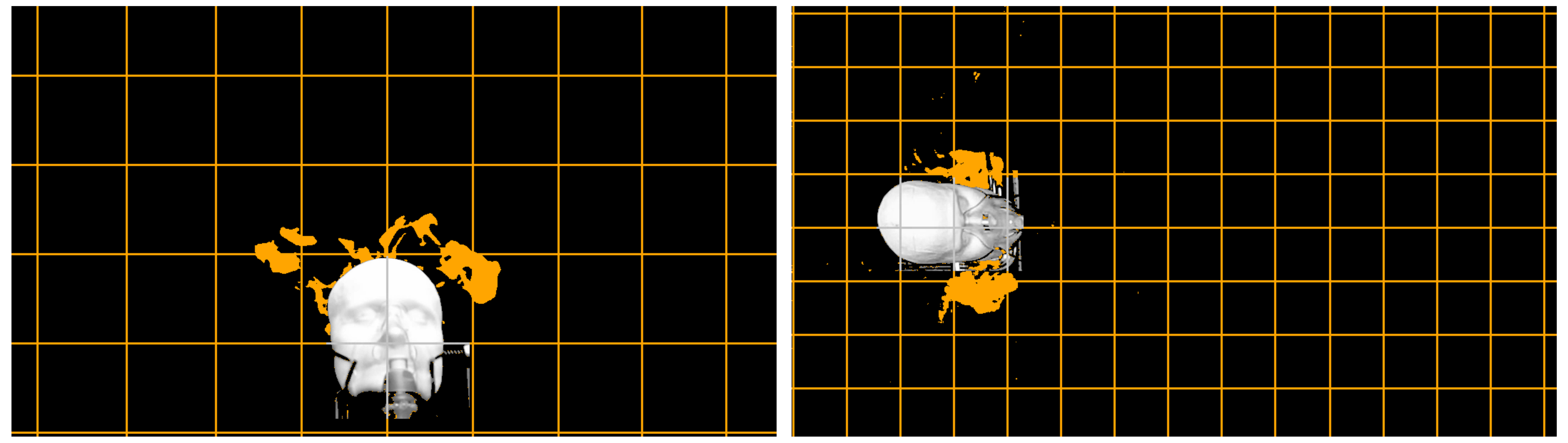

Figure: Nebulizer, 7 L/min

Discussion

More extensive jets imply a higher risk of droplet-driven virus transmission, as these jets launch and direct droplets. The exact reach of droplets is size-dependent and may be estimated from the jet velocity.

Aerosols are passive tracers, like the smoke particles. However, the visual extend of the smoke should not be interpreted as the physical extend of aerosols. Visibility of the plume is limited with decreasing smoke concentration, but single particles or aerosols keep following the air and can end-up anywhere in the room.

The filtered set-up of BiPAP and CPAP showed a plume only after the location of the filter. Virus transmission may still occur when leaks between the mask and the face are present.

Conclusion

NHF, CPAP and BiPAP showed very extensive jets, indicating high risk of droplet-driven virus transmission. For Venturi masks, non-rebreathing masks and nebulizers, this risk is comparable to normal breathing. Initial speed of the jet depends on therapy settings and possible leaks. Reach of droplets depends on jet-speed, jet-orientation and droplet size. Aerosol transport is inevitable in non-filtered support methods. Further research is needed to guide therapy set-up adjustments depending on actual infectious SARS-CoV-2 spread.

Bibliography

[1] embodi3D.com. Easily Create 3D Printable Muscle and Skin STL Files from Medical CT Scans. https://www.embodi3d.com/blogs/entry/353-easily-create-3d-printable-muscle-and-skin-stl-files-from-medical-ct-scans/, October 2016.

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