CFD SIMULATIONS OF THE CO_2 REBREATHING IN DIFFERENT HELMET-LIKE INTERFACES FOR THE CPAP THERAPY DELIVERY

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Introduction

CPAP (continuous positive airway pressure) therapy, widely used during the COVID-19 pandemic, can be delivered to the patient through helmet-like interfaces, because of their tolerability. Under low flow rate conditions, especially for closed-loop ventilation circuit [1], the CO_2 could accumulate inside the helmet, and be rebreathed by the patient (with dangerous effects for concentration values over 1% [2]). In this work, a CFD approach was developed to study the CO_2 distribution under different inlet-outlet configurations, recurring to acceptable flow rate conditions (high flows cause waste of oxygen, noise and discomfort).

Methods

The CFD simulations were performed in Fluent (Ansys). A generic helmet and human head geometry were reproduced, with a dead space of approximately 20 L. One pipe was connected to the mouth to represent the airways (~ 0.15 L) and two pipes were connected to the helmet, as inlet and outlet flow extensions, in three different layouts (Figure 1): the standard layout (A), and two novel alternatives, the one attainable only with a customized helmet (B), the other possible with a commercial one (C). CPAP was set to 10 cmH_2O.

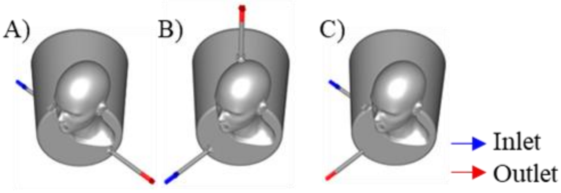

Figure 1: Helmet with the analyzed inlet-outlet layouts.

The boundary conditions for patient breathing were obtained by a lung simulator (TestChest® V3, Organis Gmbh, CH). The flow rate was set to 60 L/min and 80 L/min, for the layout A (A1 and A2 respectively), and 60 L/min, for the layout B and C. The COVID-19 patient (0.5 L tidal volume, 40 breaths/min, 5% of CO_2 in the exhalation, high respiratory effort [3]) was imposed in all cases, while a healthy subject (0.5 L tidal volume, 15 breaths/min, 4% of CO_2 in the exhalation, low respiratory effort [4]) was imposed as control in layout A (A0). The percentage of CO_2 inhaled by the patient (rebreathing in tested frontal head orientation) and the average percentage of CO_2 inside the helmet (more general information for other possible breathing directions) were calculated, setting an acceptability threshold of 1% to ensure the patient safety [2].

Results

In the standard layout (A), the CO_2 produced by the patient is confined in the mouth surrounding area (Figure 2), heavily impacting the CO_2 rebreathing (Table 1, A1). A higher flow didn't improve the washout (A2), whereas the novel inlet-outlet layouts (B-C) helped in spreading the exhaled gas distribution, with consequent reduction of inhaled CO_2.

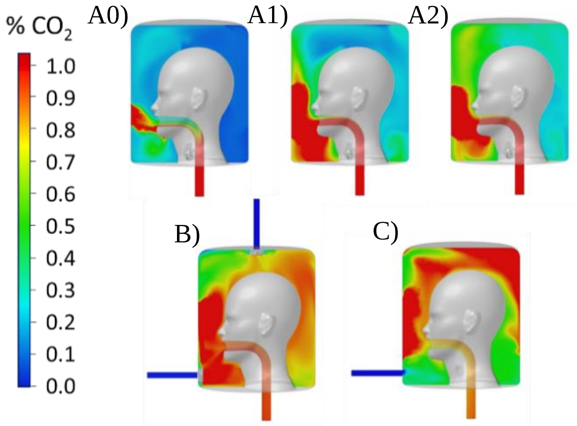

Figure 2: Comparison of the CO_2 distribution inside the helmet at the inspiratory peak (after 0.3 s), side section.

	A0	A1	A2	B	C
CO_2 av. [%]	0.264	0.593	0.597	0.880	0.886
CO_2 in. [%]	0.456	1.223	1.251	0.962	0.875

Table 1: Comparison of the average and inhaled CO_2.

Discussion

Results highlight an unfavorable effect of the flow increase on the interface washout, but a relevant impact of the inlet-outlet layout on the CO_2 rebreathing. Indeed, by adopting a frontal outlet in commercial helmets, the CO_2 rebreathing reduces by 28%. This study sheds light on the washout issue in patient's interfaces, providing novel insights in the design of optimized helmet layouts.

References

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