EXPERIMENTAL INVESTIGATION OF REBREATHING PHENOMENON IN NON-INVASIVE VENTILATION INTERFACES

Margherita De Luca (1,2), Andrea Formaggio (1,2), Giovanni Putame (1,2), Simone Borrelli (1,2), Mara Terzini (1,2) and Alberto L. Audenino (1,2)

1. Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Torino (Italy)
2. Polito^{BIO}Med Lab, Politecnico di Torino, Torino (Italy)

Introduction

Non-Invasive Ventilation (NIV) provides ventilatory support for patients suffering from acute or chronic respiratory failure without the need for endotracheal intubation or tracheotomy [1]. NIV interfaces such as helmets or facial masks are used to deliver therapy to patient during spontaneous breathing. Ensuring that there is no excessive accumulation of carbon dioxide (CO_2) during the administration of this therapy within the patient interface is crucial. This study aims to (1) experimentally quantify the extent of CO_2 accumulation in commercial interfaces and (2) identify the optimal combination of interface design and recirculation flowrate able to effectively mitigate CO_2 rebreathing.

Methods

Tests were conducted using an ad hoc experimental set-up composed by a primary turbine, capable of maintaining a 5 cmH_2O positive pressure at the patient interface, and a secondary turbine, for supplemental recirculation flowrate. To replicate the exhaled mixture of individuals with pulmonary fatigue (e.g. patient with acute respiratory distress syndrome), ambient air was mixed with CO_2 (4-5% of concentration) and delivered through a phantom mouth.

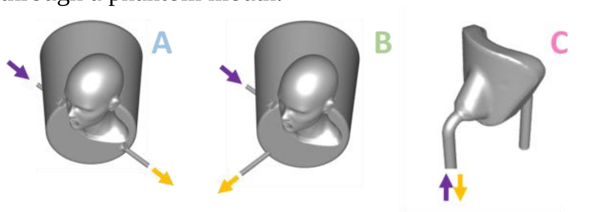

Figure 1. Tested interfaces: A) Standard helmet; B) Alternative helmet; C) Full-face mask. In purple, the inlet is represented, and in yellow, the outlet.

Three interfaces were tested (Fig. 1): a standard commercial helmet with lateral inlet and outlet (A – gold standard), an alternative helmet configuration with the outlet relocated frontally (B), and a commercial full-face mask (C). No recirculation and two recirculation flowrates (60 l/min and 80 l/min) were tested.

Results

When using interfaces A and B, the inspired CO_2 percentage decreases with increasing recirculation flowrate (Fig. 2). Indeed, in A-00 the inhaled CO_2 exceeds 2%, decreasing to 1.3% with an additional flow of 80 l/min. However, this does not bring the mean value (calculated over 35 respiratory cycles) of inspired CO_2 below 1%, considered as the acceptable threshold [2]. Acceptable levels of rebreathing can be achieved only by using the alternative helmet and a recirculation flow rate of 80 l/min (B-80). The full-face mask appears to yield the best results when used without additional flow.

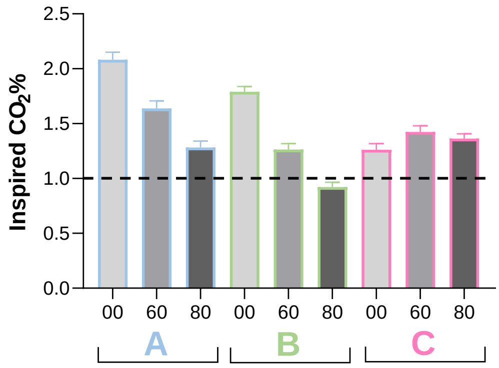

Figure 2. Mean and standard deviation of inspired CO_2 percentage across the nine tested combinations. 00: without recirculation flow; 60: with 60 l/min; 80: with 80 l/min. The black dotted line indicates the safety threshold for acceptable inspired CO_2 values [2].

Discussion

The findings of this study emphasize the importance of the outlet position in reducing CO_2 rebreathing during NIV with higher air volume interfaces. Placing the outlet in front of the patient's face (B) expedites the CO_2 release with respect to the gold standard configuration (A), especially with additional recirculation. This underscores the potential improvement in patient safety by adjusting the outlet location in commonly used helmets. On the other hand, when employing the facial mask, there appears to be no association between the introduction of recirculation and the decrease in inhaled CO_2. Although the superior performance of the mask compared to the helmet in the absence of recirculation is attributed to the smaller volume of the interface, the lack of improvement in the presence of recirculation is due to the existence of a single opening for both inlet and outlet.

References

1. Popowicz P." Noninvasive Ventilation and Oxygenation Strategies" Surg Clin North Am. 2022
2. NIOSH. "Occupational exposure to carbon dioxide." 1976

Acknowledgements

This work is part of the NODES project (MUR – M4C2 1.5 of PNRR, grant agreement no. ECS00000036)