FLUID DYNAMIC ANALYSIS OF AREOSOL ACCESSORIES: THE MOUTHPIECE

Luca Possenti, Giustina Casagrande, Maria Laura Costantino

Department of Chemistry, Materials and Chemical Engineering "Giulio Natta", Politecnico di Milano, Italy

Introduction

Many Computational Fluid Dynamic (CFD) analyses about aerosol deposition in the human airways are reported in the literature [1]. However only few studies analysed the pathway of aerosol particles from the nebulizer to the mouth (e.g.: through mouthpieces or face masks). This analysis is important to properly describe the fluid dynamics at the outlet of these devices in order to define particles trajectory so as to highlight the site of deposition [2]. Aim of this work is to study the fluid dynamics in the mouthpiece, that is considered as the gold standard for aerosol delivery, by a CFD approach [3]. This will give a reference for further evaluations of other accessories performance.

Methods

Fluid domain geometry was built from a commercial mouthpiece. After sensitivity analysis, a tetrahedral mesh with about 1.8 million of elements was chosen. An experimental validation was performed with water using dynamic similarity theory (at the same Reynolds number) [4], in order to identify the best model to be used among laminar model, enWF k-ε and low Re SST k-ω model: the k-ω model was chosen. Velocity profile at the inlet, a reference pressure of 0 Pa at outlet and no-slip condition at the walls were set as boundary conditions. An RC model was implemented to simulate the patient's airway conditions: a constant resistance and a variable lung compliance were defined based on the literature [5]. A range from 0.5 to 10 µm of nebulized particles (saline solution, $\rho = 1009\ kg/m^3$) diameter was considered and divided into 12 intervals; a sensitivity analysis on the particles number was performed: 2000 particles were simulated for each diameter interval, resulting in 24000 particles. Both one and two ways coupling were tested, resulting in not significant differences: one way coupling was thus used to save computational time. Particles mass flow rate at the inlet were tuned, for each interval, with experimental data acquired from tests on two commercial compressors (Compr.1, Compr.2) with two different nebulizers (Neb.1, Neb.2). Different boundary conditions were set for discrete phase: total reflection of particles at the wall, and escape from domain at the outlet. Simulations were performed considering different particles inlet conditions for each compressor-nebulizer couple. Results were evaluated in terms of velocity, pressure, turbulence and particles fate. Deposition site was evaluated referring to UNI EN 13544-1 guidelines that define the particle deposition preferred site as function of particle diameter ($Ø_p$): alveolar site $Ø_p < 2.5$ µm, tracheobronchial site $2.5\ µm < Ø_p < 5.5$ µm, upper airways site $Ø_p > 5.5$ µm.

Results

The pressure drop generated by the air flow through the mouthpiece was 0.35 cmH_2O; mean velocity at the outlet increased from 2.4 m/s to 4.9 m/s due to section reduction. Turbulence was produced downstream the curvature of the mouthpiece; about 99% of particles were delivered at the outlet in all the conditions analysed. Recirculation of particles due to vortexes involved only 1% over the total amount, and was made up mainly by bigger particles. The mean angle between velocity and normal vector at the outlet was 11 ± 2°.
Particles Mass flow rate for each compressor-nebulizer couple is reported in Figure 1.

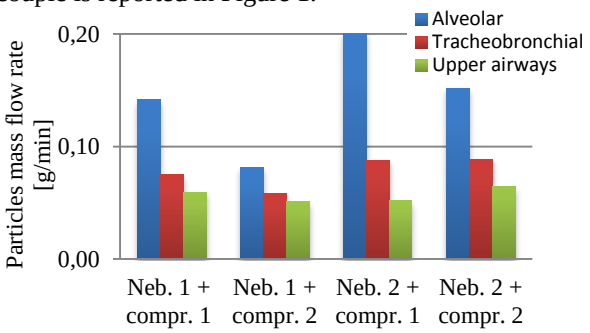

Figure 1: particles mass flow rate calculated at the outlet of the mouthpiece with estimation of deposition site (UNI EN 13544-1 guidelines).

Discussion

The developed model allows a quantitative analysis of aerosol particles velocity, recirculation, direction and delivery, also classifying particles by their diameter. This CFD method can provide additional information to current laboratory experimental evaluation of nebulization rate and delivery, and can be used also to compare the performances of other aerosol delivery accessories.

References

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