PIV on the flow of a simplified upper airway model

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Inhaled medication is available since many years for the treatment of asthma and other chronic pulmonary diseases. It is important that the aerosols containing the medications effectively reach the alveolar zone of the lungs. A certain part of the dose will deposit on the walls of the extra-thoracic airways (mouth-throat zone). This passage has a highly irregular shape with a mouth section, a 90 degree bend and the passage through the vocal cords. When the air enters the mouth by inhalation it passes through the pharynx and enters the trachea via the larynx which contains the epiglottis and the vocal cords. The severe constriction caused by the vocal cords causes the flow to accelerate resulting in a laryngeal jet. The laryngeal jet affects the aerosol transport in three ways; it induces the formation of recirculation zones and eddies, influences the momentum and the direction of the particles and, increases the turbulence levels.

It is therefore important to know the turbulence levels in the larynx and trachea to verify the different numerical models.

Data provided by the Department of Pneumology of the academic hospital of the Vrije Universiteit Brussel, of several male subjects during the inspiration phase of the inhalation cycle, were imported into the Amira software and smooth 3D-geometries were created. These data contained cross-sectional CT-scans of the upper airways at every 5 mm. Specialists in the field of human respiration selected the most appropriate realistic geometry. By use of Computational Fluid Dynamics (CFD) simulations, an idealized 3D geometry was created in such a way that the main flow characteristics were preserved.

The use of Particle Image Velocimetry (PIV) to measure an internal flow requires non-reflecting boundaries since reflections cause distorted images near the boundaries. Therefore, the refraction indices of the fluid and the silicone should match. When using a glycerin-water solution for the fluid this property is satisfied. The viscosity of the glycerin/water mixture had to be known, so that Reynolds number matching could be applied. The viscosity of the mixture depends on temperature and had to be accurately measured at operating temperature, which was around 27.3°C. The viscosity of the mixture was 5.38 10^{-6} m^2 /s at this temperature.

The model is not scaled and consequently the Reynolds number matching amounts to:

$$Q_{\text{air}} = \frac{\nu_{\text{air}}}{\nu_{\text{mixture}}} Q_{\text{mixture}}$$

where Q is the volumetric flow rate and ν is the kinematic viscosity.

Measurements were performed in a central sagittal at three different flow rates: 40, 20 and 13.3 l/min air flow rate representing quit breathing (13.3 l/min) and normal breathing (20 to 40 l/min).

Figure 1 show the magnitude of the velocity in a central sagittal plane of the model at two different flow rates (20 and 40 l/min air flow rate).

The results show the complex nature of the flow in this idealized model. Several regions of recirculation in mouth, pharynx and trachea show the possible existence of three dimensional flows.

The normalized turbulent kinetic energy in the central plane at an air flow rate of 40 and 20 l/min is very similar while in the case of 13.3 l/min the region is shifted towards the end.

The laryngeal jet in case of 20 and 40 l/min air flow rate decays faster and is a little bit wider compared to the jet in case of 13.3 l/min air flow rate.

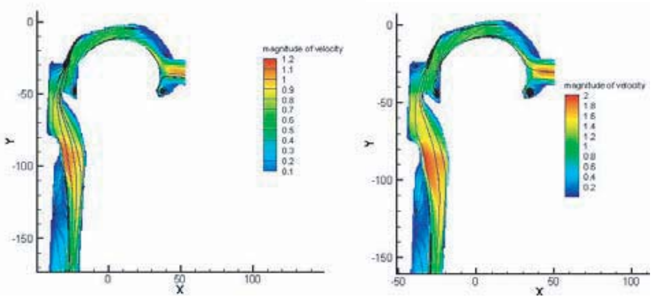

Fig. 1 Magnitude of velocity and streamlines in an idealized model of the upper human airways (left: 20 l/min air flow rate; right: 40 l/min air flow rate)