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Flow Dynamics of Inspiration

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INTRODUCTION

The air we breathe in follows an intricate path before it reaches the delicate tissues of the lungs where gas exchange occurs. The flow is first split between the left and right nasal cavities and made to rotate by 90 degrees. Within each cavity, the air stream is further divided by protruding structures known as the turbinates. In the nasopharynx the streams from both sides of the nose undergo a further 90 degree rotation before entering the larynx and emerging as a jet into the trachea. The dynamics of the airflow has important consequences for physiological functions, including heat and water exchange in the nose and nasopharynx, olfaction and the flow induced loading on the surrounding tissues. Here we report results from a computational simulation of a short inspiration, illustrating the broad range of flow conditions that pertain during inspiration.

METHODS

Temporal profiles of inspiratory flow were measured using fast response hot wire probes as reported in *Rennie* et al[1]. A sample measured trace, representative of a short inhalation lasting 0.5 seconds, was used to define the inspiratory profile resulting in a ramp to 1200 ml/s in 0.1 s, a plateau region for 0.3 s and then decay. The airway geometry was extracted from a Computerised Tomography (CT) scan of a subject reported as normal by a consultant radiologist. The simulated geometry extends from a hemisphere 0.5 m in front of the subject's face down to the fourth bronchial branch.

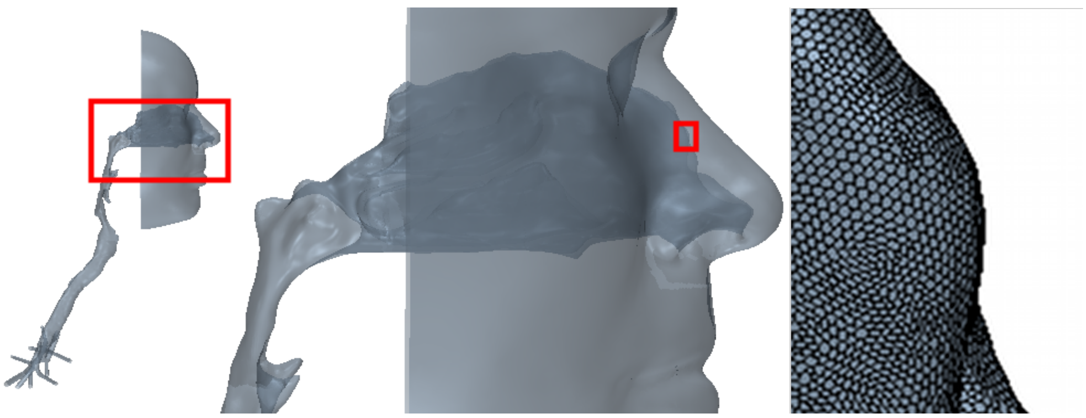

Figure 1: Anatomy and mesh

Once extracted, this surface was then meshed using a combination of prism and polyhedral cells using Star-CCM+ 8.04.007 (CD-adapco). Direct Numerical Simulation (DNS) large scale computation of the Navier-Stokes equations was applied to resolve instantaneous flow at a time resolution of ~0.01 ms per time step throughout.

RESULTS

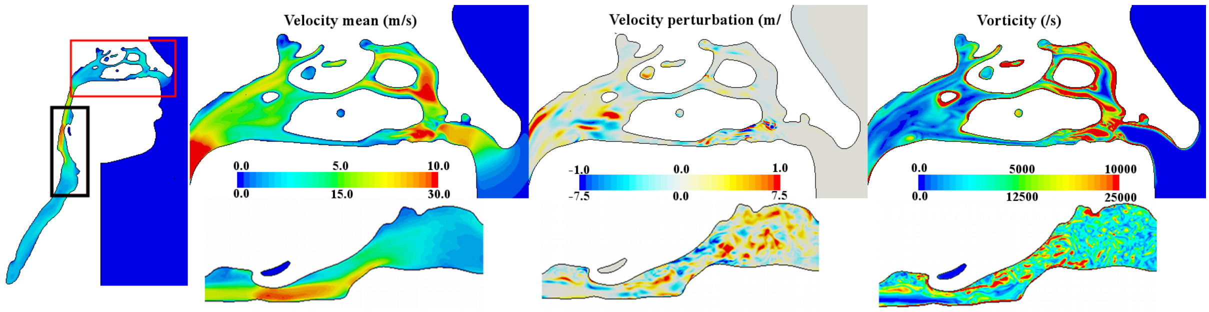

Figure 2: Sagittal sections – upper images show the detail in the red box, lower images show the detail in the black box rotated anti-clockwise by 90°

The variation in the velocity of the inhaled air, averaged over a short temporal window near peak inspiration, throughout the large airways is illustrated in figure 2, leftmost panel. This simulation shows a peak flow rate in the region before the glottis, which is the narrowest constriction for the subject geometry. The velocities in this region are approximately three times those at the corresponding instant in the nasal airways.

Details of the flow in the nose and the region of the glottis are shown in figure 2. The inhalation rate at this point during inspiration corresponds to 1150 ml/s, inducing peak velocities of 10 m/s in the nose and 30 m/s in the glottic region. The velocity perturbations are also higher in the latter region (reaching 25% of the local mean velocity) than occur in the nose, where the perturbations are generally less than 10% of the local mean. The flow pattern is found to differ between the two nostrils, due to the different shape of the nasal valve in each side causing a more pronounced jet in the right nostril.

High regions of vorticity in the nose highlight the thin, fresh boundary layers found where the jet from the nasal valve impinges on the middle turbinate, as well as the margins of free shear layers. A similar pattern is found in the jet around the epiglottis and base of tongue regions before the jet breaks up as it approaches the glottis, leading to a highly disturbed downstream flow. Transitional flow is observed in the anterior part of the nasal cavity whilst the breakup of the flow downstream of the laryngopharyngeal jet produces a turbulent flow.

These highly resolved simulations also provide a reference point regarding the numerical resolution required to create accurate models of flow dynamics within the upper airways, depending on the quantities of interest.

REFERENCES

[1] Rennie CE, Gouder K, Taylor DJ, Tolley NS, Schroter RC, Doorly DJ, 2011, Nasal inspiratory flow: at rest and sniffing, *International Forum of Allergy & Rhinology*, Vol:1, 2042-6976, Pages:128-135