Pulsatile flow in the nasal cavity with high flow therapy measured by stereoscopic PIV

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The primary function of the nasal cavity is to filter, warm and humidify inspired air before it reaches the lungs, while providing olfactory function. All these functions are dependant on the flow field in the nasal cavity. Nasal cannulae are used to administer a breathing ventilation therapy known as nasal high flow (NHF). Cannulae therapy until recently has been limited to low flow rates due to the discomfort and irritation caused by delivering dry, cold gas to the nasal passages. NHF, however, delivers to patients heated and humidified air at body temperature and 100% humidity at steady flows ranging from 5–50 l/min via a nasal cannula. Most measurements of the flow in the nasal cavity conducted to date have assumed quasi-steady conditions based on a small Womersley number for quiet breathing of around 3; however, uncertainty still remains whether the flow can be modeled as steady. In this study, the flow velocities in the nasal cavity across the complete respiratory cycle during natural breathing and with NHF flow have been mapped in-vitro using time resolved stereoscopic particle image velocimetry (SPIV). As well as contributing to the understanding of the airflow through the nasal cavity during natural breathing, these measurements also help to elucidate the effect of assisted breathing on respiratory mechanics and patient comfort.

2. Experimental Method

A 1.55 scaled silicone resin model of a human male adult nasal cavity (Figure 1) was constructed using a technique employing CT scan data and rapid prototyping. A model of the nasal cannula was built in stereolithography resin, also scaled 1.55 times. The models were submerged in a tank and connected to a closed loop flow circuit containing 61% glycerol in aqueous solution. At this composition the refractive index of the silicone was matched, allowing an undistorted view through the nasal cavity's complex surfaces. A reciprocating piston pump driven by a ball screw and stepper motor was constructed to provide a physiological breath waveform in-vitro. Breathing waveforms were measured in-vivo during natural breathing and with NHF on a healthy 23 year-old male with height 184 cm and weight 85 kg. Dimensional similarity between was maintained by Reynolds and Womersley number matching. The SPIV system consisted of a 15 Hz dual-head 120 mJ Nd:YAG laser (New Wave Solo XT), two digital 2 mega pixel CCD cameras (Dantec Flowsense) and optics to form a light sheet of approximately 2 mm thickness. The working liquid was seeded with near neutrally buoyant 10 µm hollow glass spheres.

3. Results

Presented are the results for both natural breathing and breathing assisted with NHF from 8 of the 15 time steps measured through one sagittal cross-section of the nasal cavity that bisects the left nostril.

4. Conclusions

SPIV has been used to measure the distribution and velocity of the airflow in the nasal cavity with physiologically reproduced pulsatile flows for natural breathing and breathing assisted with NHF. The flow pattern in the nasal cavity differed significantly with and without NHF. Preliminary results have been shown that suggest a quasi-steady flow assumption for natural breathing is inaccurate, however, time dependency was not found with NHF.