Experimental setup for high spatial resolution flow visualization in upper human respiratory tract

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I Introduction

The nose is part of the upper airways and has a complex three-dimensional geometry. The passageway for air narrows at the nasal valve and widens as it reaches the mid-section at the site of the nasal turbinates. Enclosed to nasal cavity are four groups of paranasal sinuses shown in figure 1. Paranasal sinuses are air-filled [1].

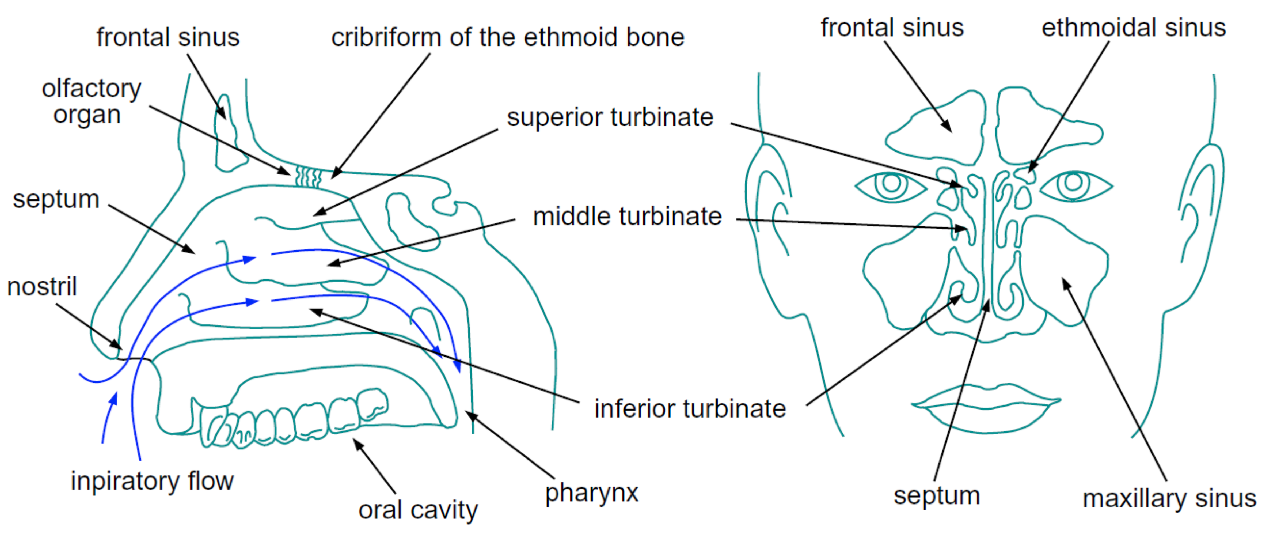

Fig1 Frontal (right) and sagittal (left) view of nasal geometry including paranasal sinuses [2].

Nasal disorders strongly influence the functionality of the entire airway e.g. function of the lungs as well as healthy sleep. The increasing demand of treatment methods like drug application in nasopharynx brings an enormous interest in exact understanding of nasal flow conditions. Additionally, surgical corrections for diseases in human respiratory tract e.g. atrophic rhinitis [3] and empty nose syndrome [4] are necessary.

II Problem statement and research question

To improve diagnostic precision, preoperative planning and minimizing rate of surgery failures a detailed consideration of the human airways is necessary. Nasal surgery is a field where surgeons need objective indicators to support them in choosing the surgical technique suitable to every particular patient, in relation to his/her specific anatomical and functional features [5]. Additionally medical practitioners are increasingly using digital simulations for patient individual medicine: The quality of numerical results of turbulence models depends on various reasons e.g. grid quality, boundary conditions and computational model of fluid [6]. For this reasons, it is important to validate numerical models by an exact experimental work.

III Research approach and methodology

The geometry of the real nose cavity was extracted from a computer tomography (CT) data set. Figure 2 shows a scheme of the experimental tomo-PIV setup with neccessary components.

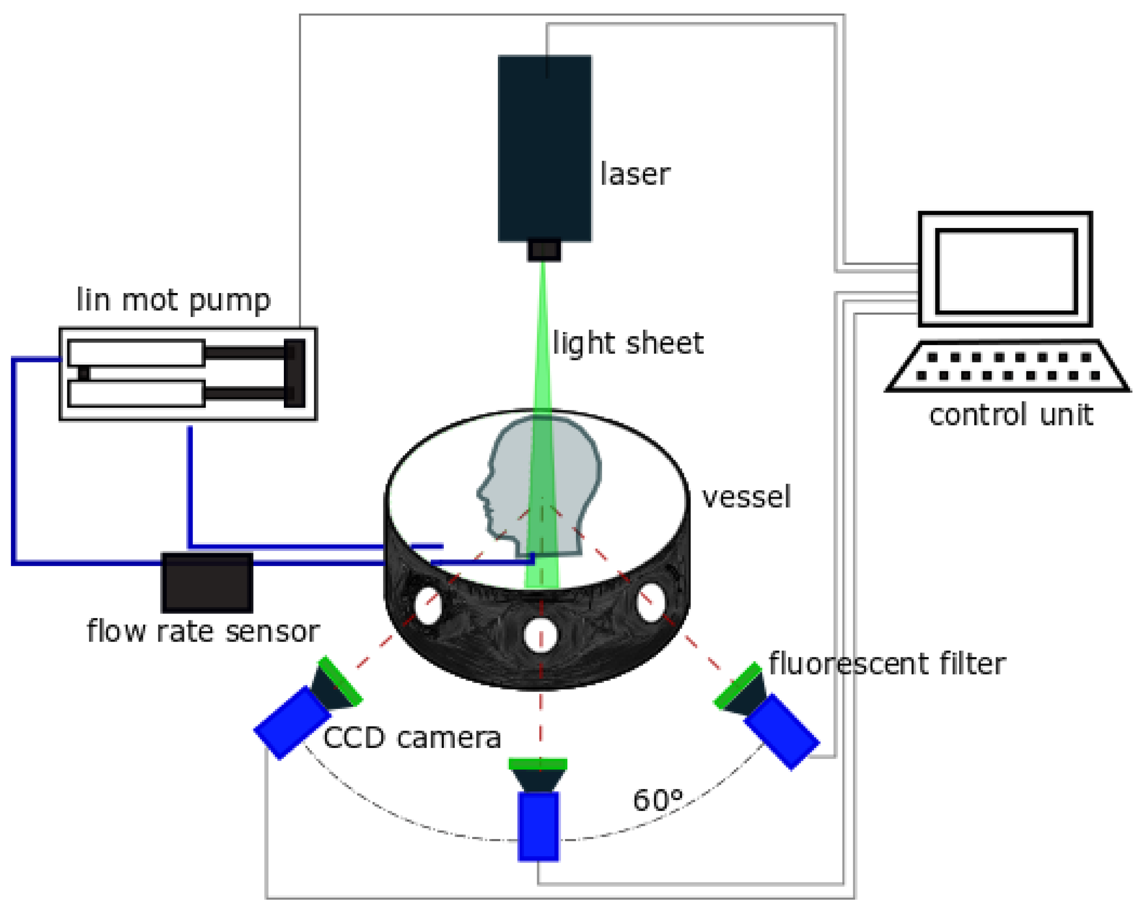

Fig2 Tomo-PIV setup.

The geometry of the real nose cavity was extracted from a computer tomography (CT) data set. To pay attention to the sinuses a two part gypsum mould was constructed as shown in figure 3.

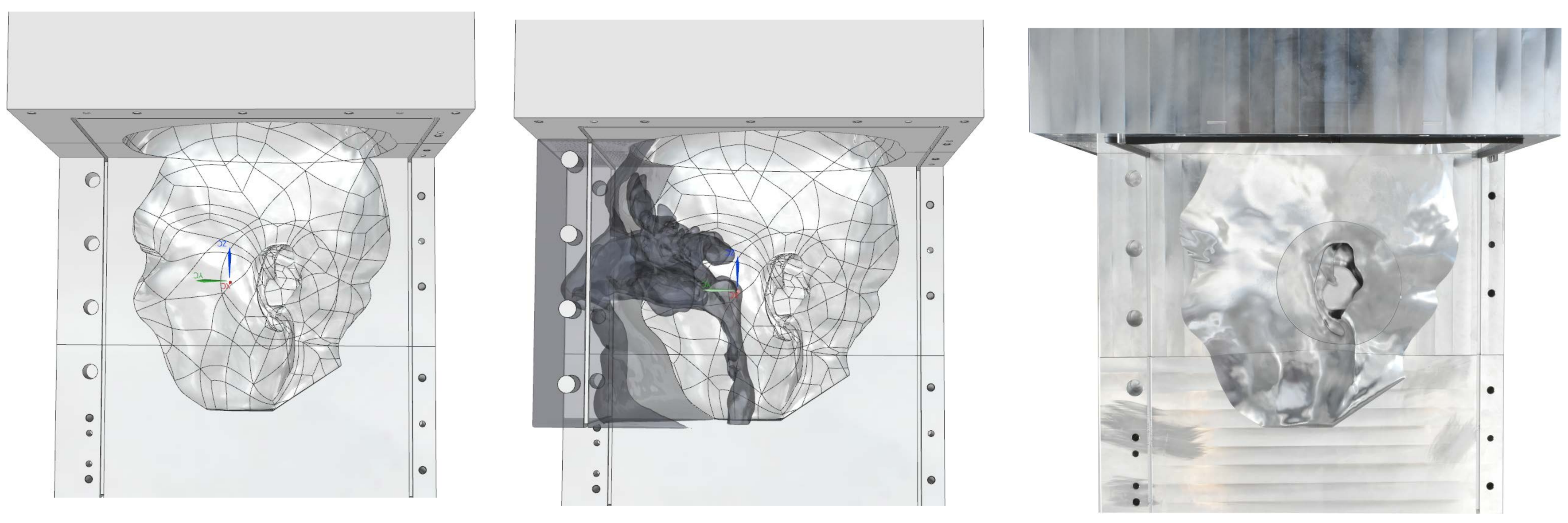

Fig3 CAD sketch w/o nasal geometries (left) and manufactured aluminium mold (right).

The mould was based on a clinical computer tomographic scan of a test person. After CT-scan the images were post processed and extracted by an otorhinolaryngology specialist to pay attention on all relevant parts including paranasal sinuses. After post-processing of clinical CT-scan a gypsum mould was manufactured by rapid prototyping (figure 4).

III Research approach and methodology (extension)

Fig4 Rapid prototyped trachea (left) and nasal geometry (right).

Optical measurements need refractive index matching. For Sylgard 184 ($n \approx 1.418$) water glycerol mixture in ratio 65:35 at 20°C is needed. To fill in water-glycerol a vessel with minimum diameter of traverse travel range to cover up the full head geometry is required. Therefore, a PVC bag with three portholes (BK7 glass) was constructed. Angles between each porthole will be adjusted to 60°. Radially the bag was reinforced by 5 wooden frames as shown in figure 5.

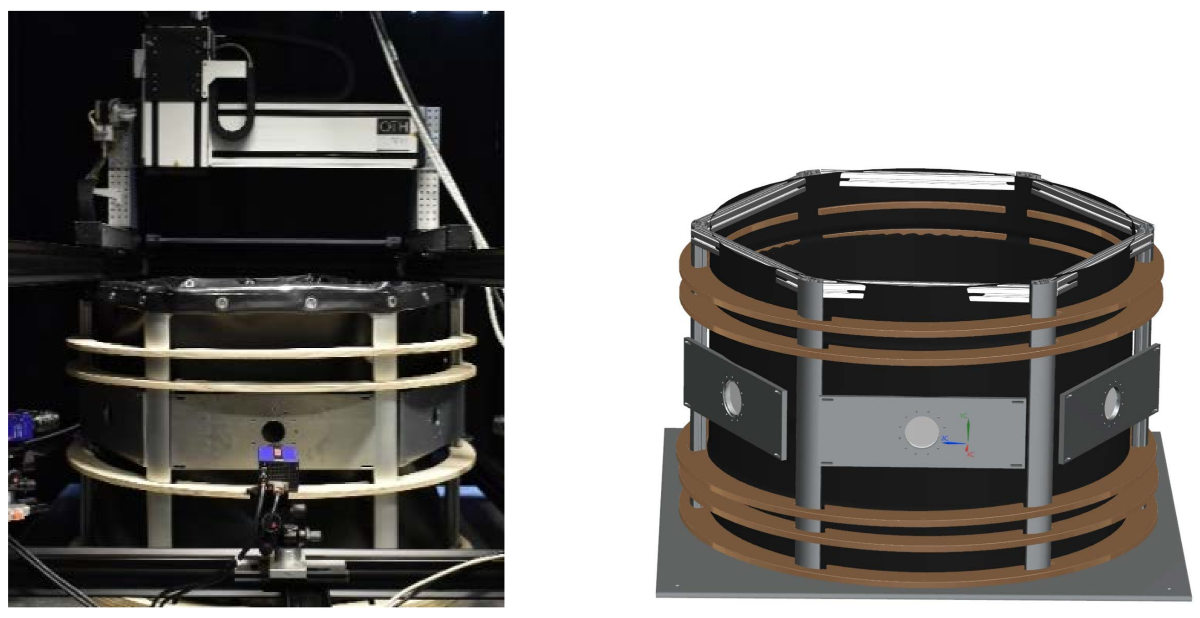

Fig5 Vessel for refractive index matching.

Due to the fact, nasal flow is a 3D flow, tomo-PIV measurements are necessary. Tomo-PIV system (LaVision) with three cameras with CCD sensors and macro objectives (ZEISS Milvus 2/100) will be used. For instationary flow conditions phase-locked method will be used. Light source will be a double pulsed Laser (EverGreen 70-200 mJ @ 532 nm). Fluorescence particles to ensure precision were planned to use. To look at velocity vectors at unsteady flow a pump with two linear motors was constructed. The pump is digital controlled to ensure a reproductive sinusoidal as well as an averaged typical volume flow during breathing as shown in figure 1. Pressure drop will be regarded by pressure sensors.

IV Results and Discussion

Besides experimental studies numerical approaches regarding nasal flow in nasopharynx are well established. For assumptions of laminar flow conditions in nasal cavities different numerical models for turbulent flow still exist. Besides this experimental data is rare. In several investigations stereo PIV measurements with nose similary models were conformed. Whereby a steady or sin-wave flow is considered. Due to the impact of turbulence flow on air conditioning it is important to consider also those flow regimes exactly. Furthermore it goes without saying, experimental validation is necessary. Even so, the whole nasal geometry must be taken into account. To get an overview about flow patterns in the nasal geometry Computational Fluid Dynamics calculations (CFD) using FLUENT (ANSYS Inc.) were prepared (figure 6). Therefore a stationary flow with mass flow 1.225 kg/m3 was assumed. Numerical procedure for calculations was Semi-Implicit Method for Pressure Linked Equations-Consistent (SIMPLEC algorithm).

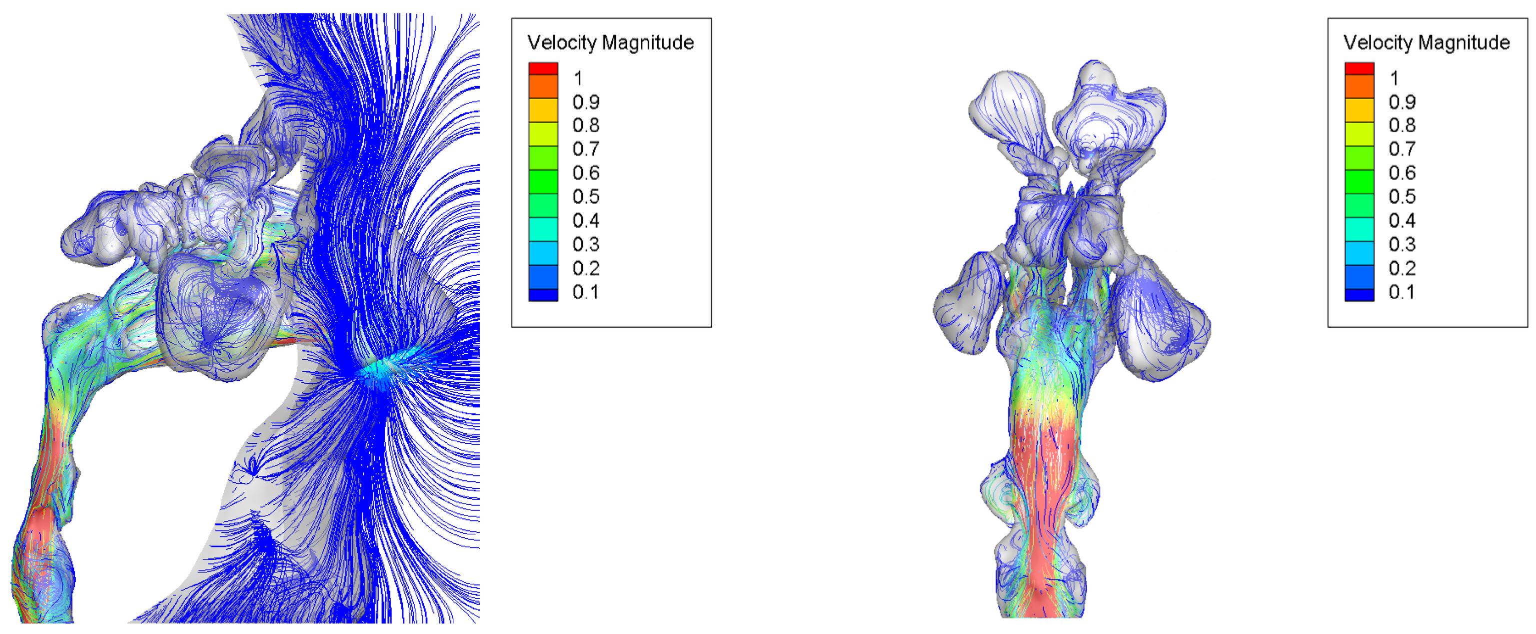

Fig6 Calculated pathlines in sagittal and frontal view of nasopharynx.

As shown in figure 6 paranasal sinuses show pathlines. Another part is a unsteady flow condition. Since breathing pattern do not follow sin wave function, the whole breathing cycle must be considered. In case of the fact, small instationary flow conditions influence health condition a high spatial resolution tomo PIV measurement is necessary.

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