Improvement of Tomo-PIV Analyses in the Nasal Cavities

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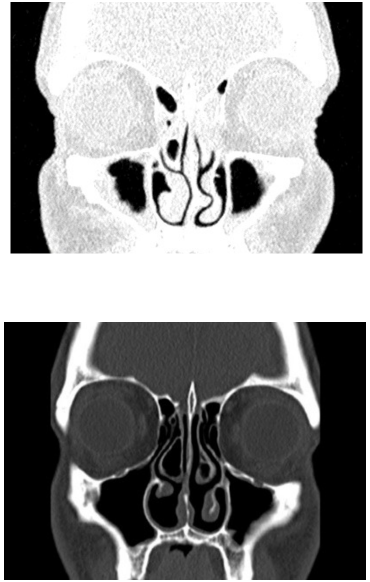
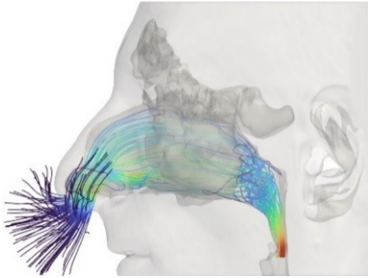
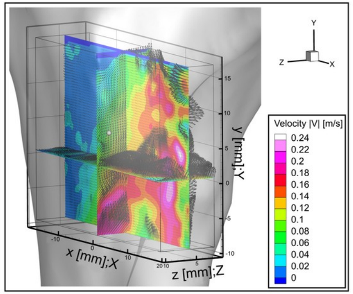
Clinical



Numerical



Experimental



Overall objective: bringing CFD into the clinical setting

Patient-specific CT-scan

CFD solution

Implementation into surgical treatment

CFD enables the improvement of:

- Diagnostic precision
- Successful surgical outcomes

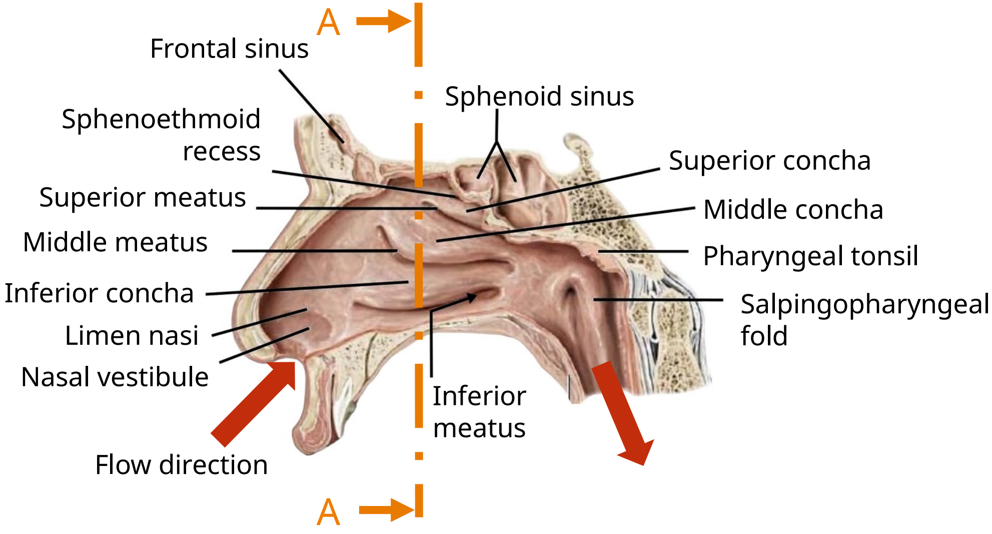
➡

Checking the reliability of the numerical model through a solid benchmark by

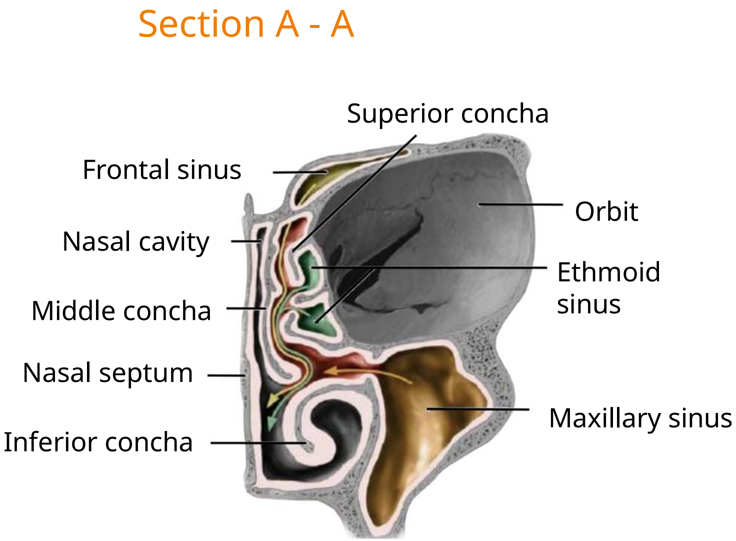
Experimental Investigations

Human Nose - Functions and Anatomy

Lateral nasal wall, sagittal section, medial view [1]



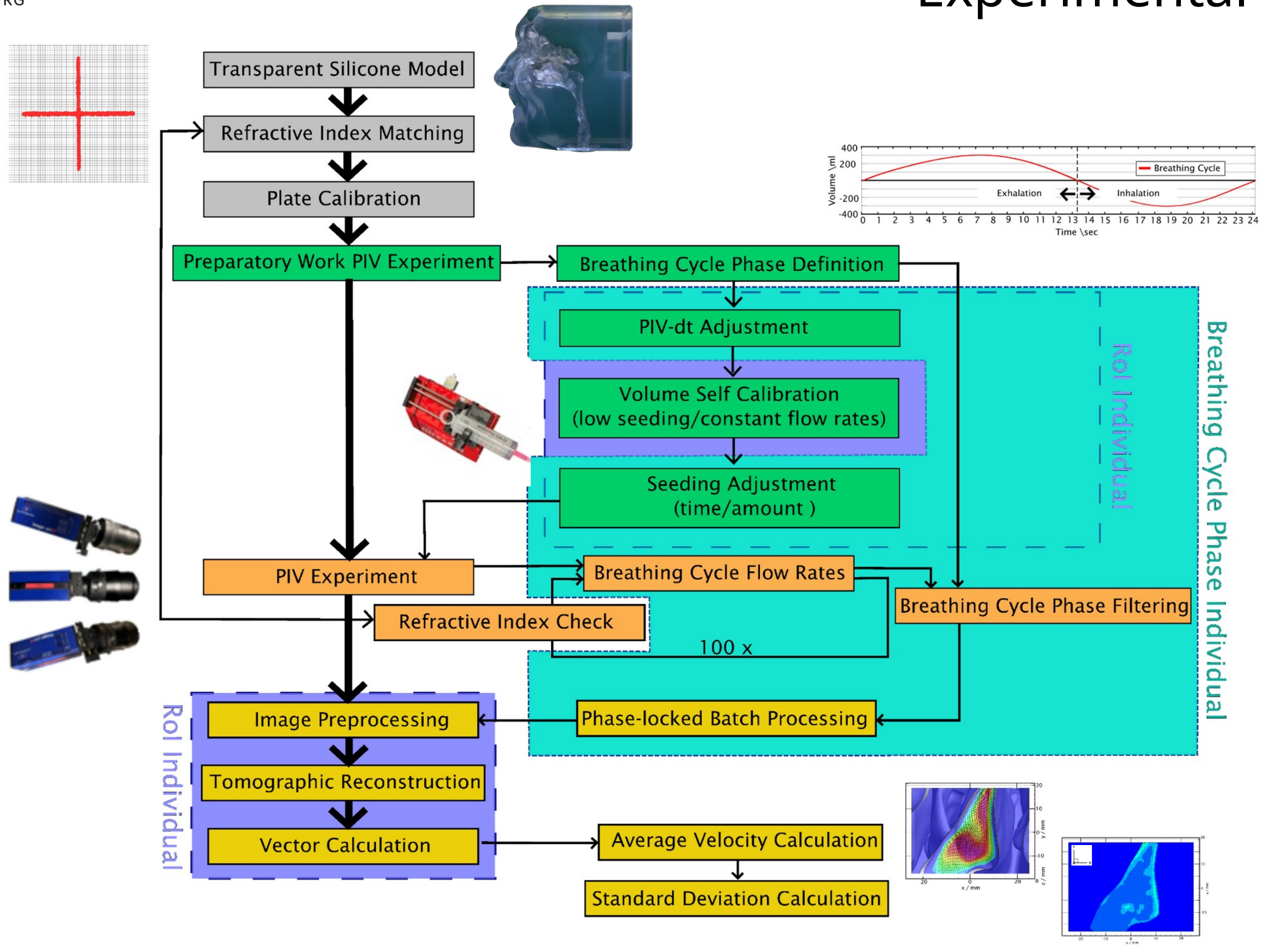
Paranasal sinuses, coronal section, anterior view [1]



Highly complex, inter-individually varying geometry

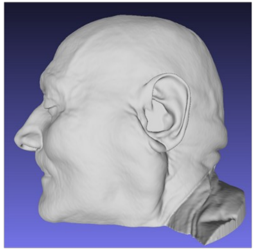
[1] Gilroy, A. M., MacPherson, B. R., Ross, L. M., Broman, J., & Josephson, A. (Eds.). (2008). Atlas of anatomy (pp. 356-450). Stuttgart: Thieme.

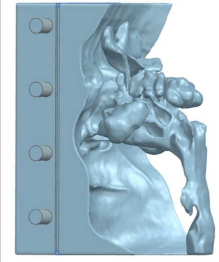
Experimental Procedures

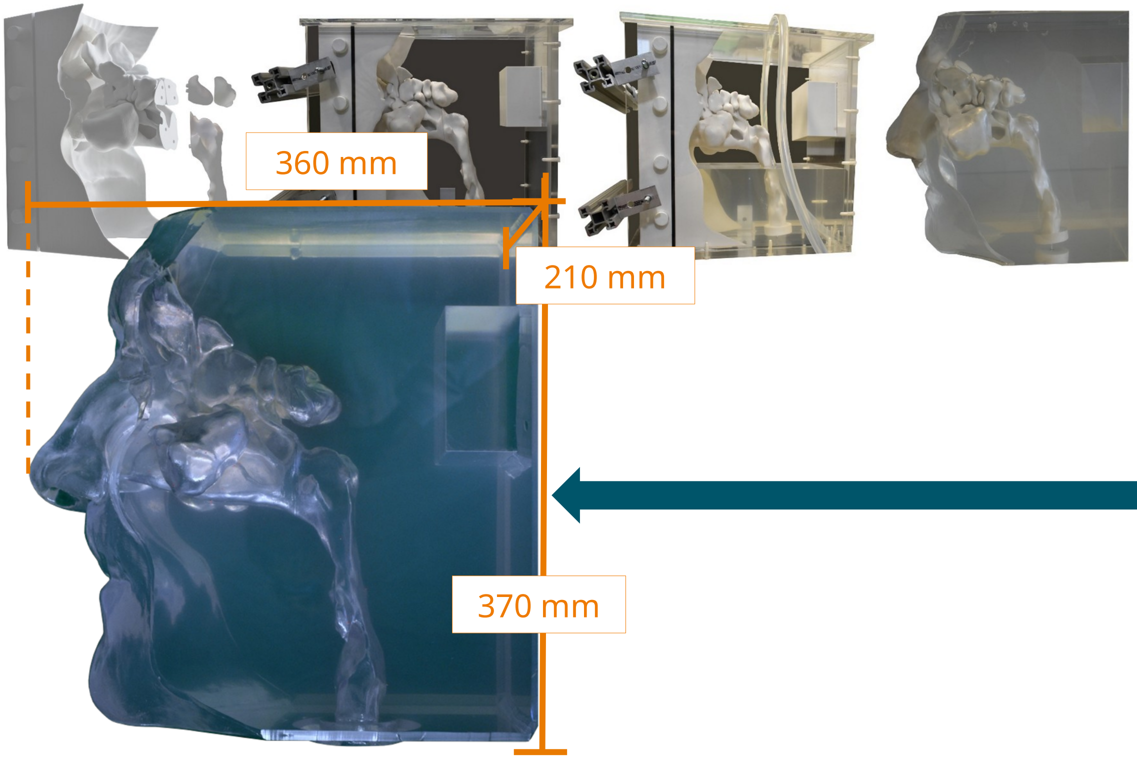


Transparent Silicone Model

CT Scan → STL Geometry → Rapid Prototype → Casting → Silicone Filling → Curing & Removing





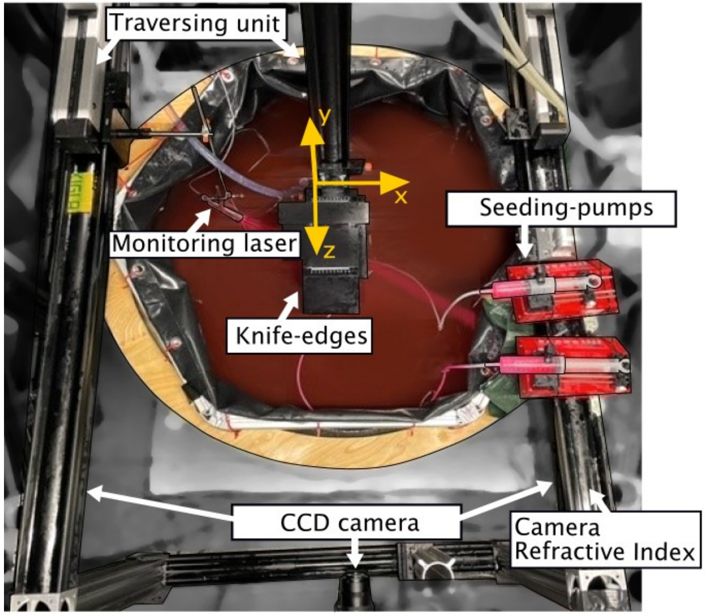


Transparent Silicone Model

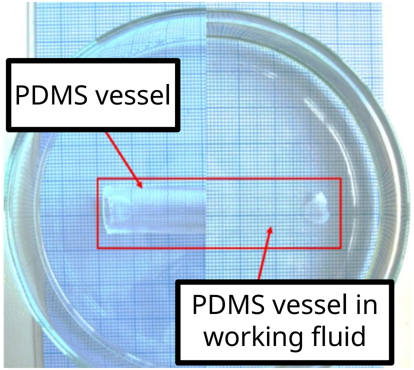
- Polydimethylsiloxane (PDMS)
- Two-component silicone
- $n_{(PDMS)}$ = 1.414 (material data sheet)

Experimental Setup

- 800 L **fish tank** containing three portholes
- **3-axis traversing unit** (isel Germany AG)
- **CCD cameras** (Imager Pro X 2A, 1600x1200 pix)
  - Macro lenses (Milvius 2/135, ZEISS)
  - Scheimpflug adapters
  - Cut-off filters
- **Light source** dp Nd:YAG laser (EverGreen200, 70-200 mJ @ 532 nm, 15 Hz)
- Trigger signal from control unit (PLC) starts **linear-motor-driven piston pump**–> induces modified **breathing cycle**
- **Fluorescence tracer particles** (PMMA-RHB, 20-50 um, abs/emm =560/584 nm)
- Two **seeding pumps**
- **Refractive Index Monitoring** laser and camera



Refractive Index Matching



Non-free-of-sight tomo-PIV requires Refractive Index Matching:

- $n_{(water)} = 1.333$
- $n_{(glycerol)} = 1.473$

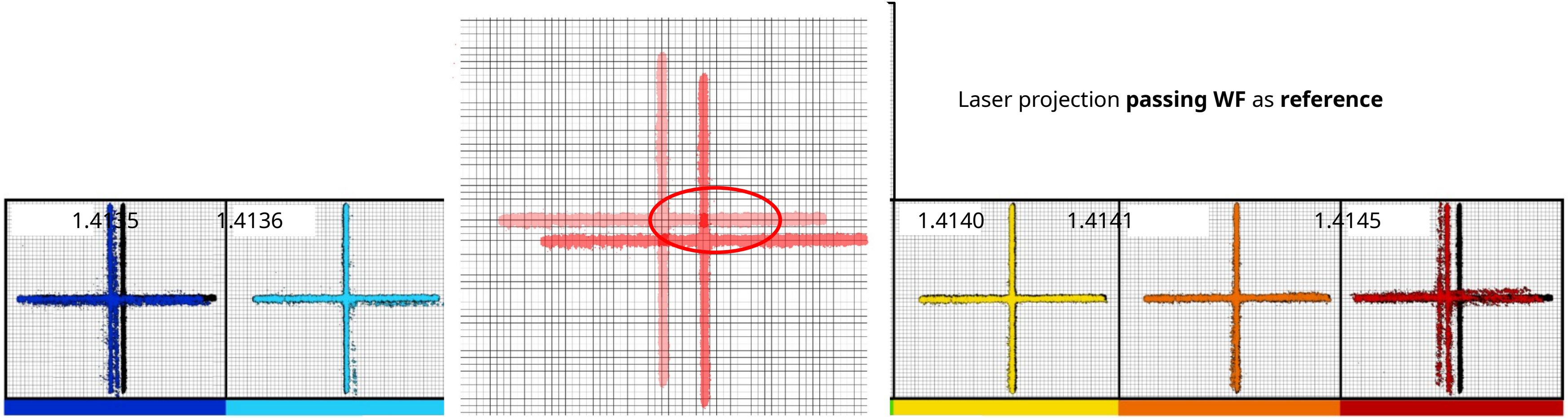
$\left.\begin{matrix} \\ \end{matrix}\right\}$ working fluid

- $n_{(PDMS)} = 1.414$ (material data sheet)

Problem:

- Customers value changed during processing
- Separation of the working fluid‘s components

➡ Unsuccessful VSC results !

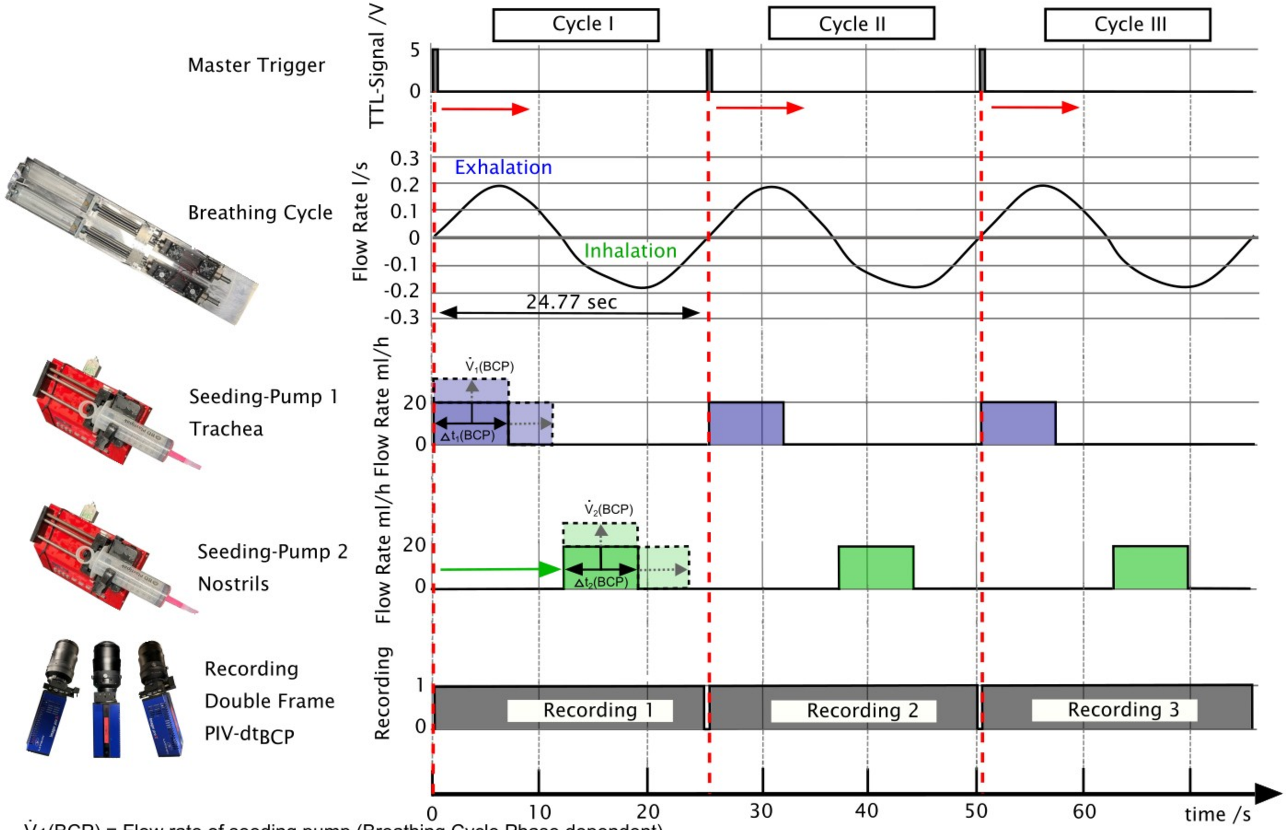


Laser visualization moves due to RI mismatch

ing different RIs

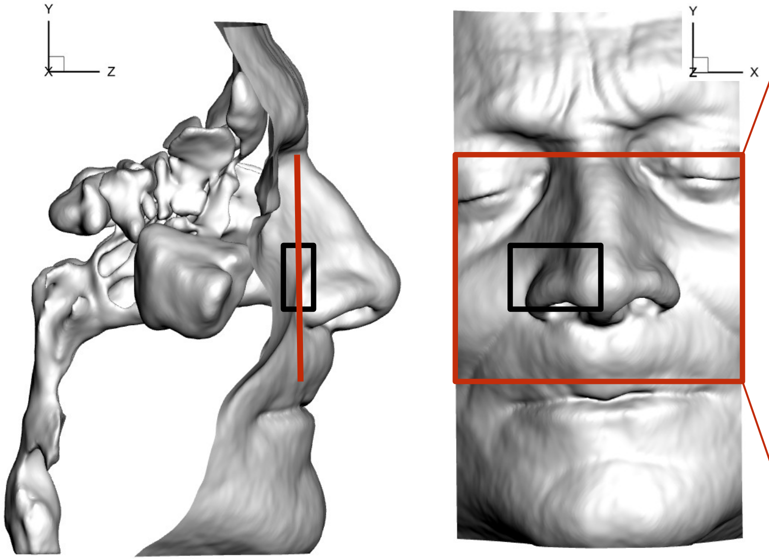
OSTBAYERISCHE TECHNISCHE HOCHSCHULE REGENSBURG

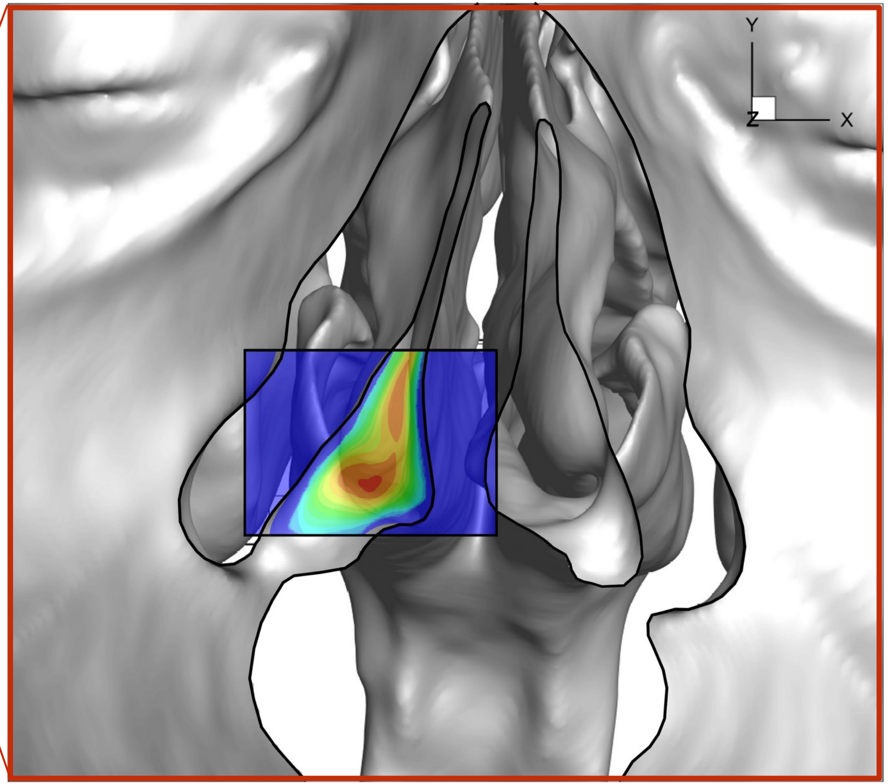
Timing / Device Control



$\dot{V}_1$(BCP) = Flow rate of seeding pump (Breathing Cycle Phase dependent)
Δt_2(BCP) = Seeding time of seeding pump (Breathing Cycle Phase dependent)

Results - Nostrils

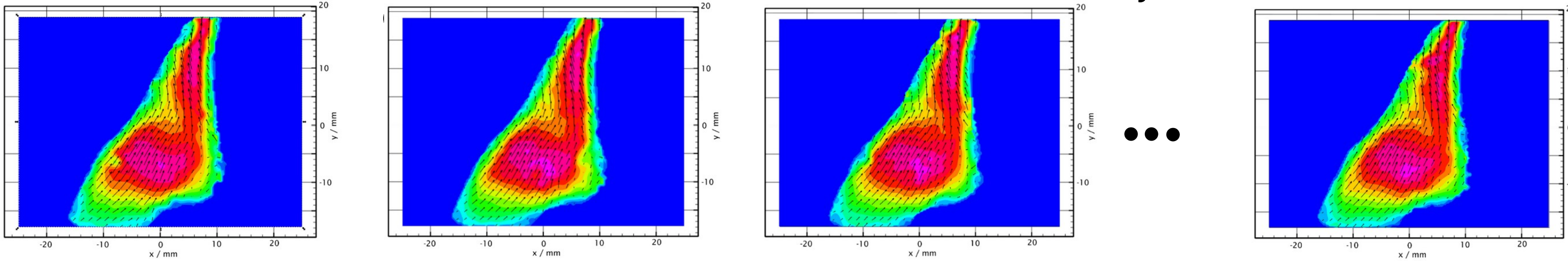




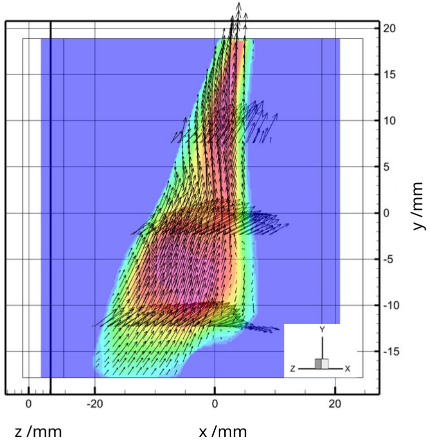
FoV = 49.5 mm x 36.5 mm
RoI = 49.5 mm x 36.5 mm x 4.5 mm
Scale factor = 29.1 pix/mm
VSC error < 0.1 pix

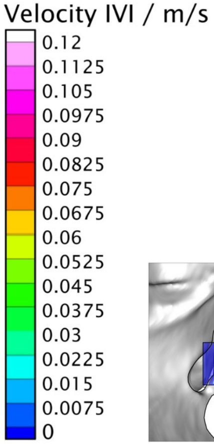
Results – Averaging Cycle Phases

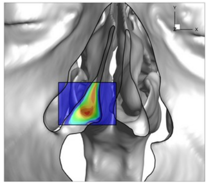
Cycle 1 **Cycle 2** **Cycle 3** ...



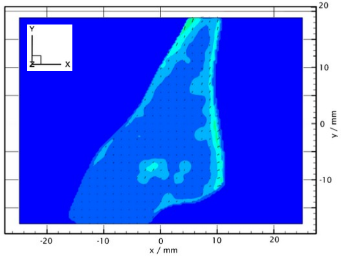
Averaged 3D Velocity Field



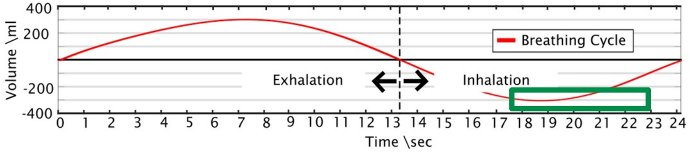


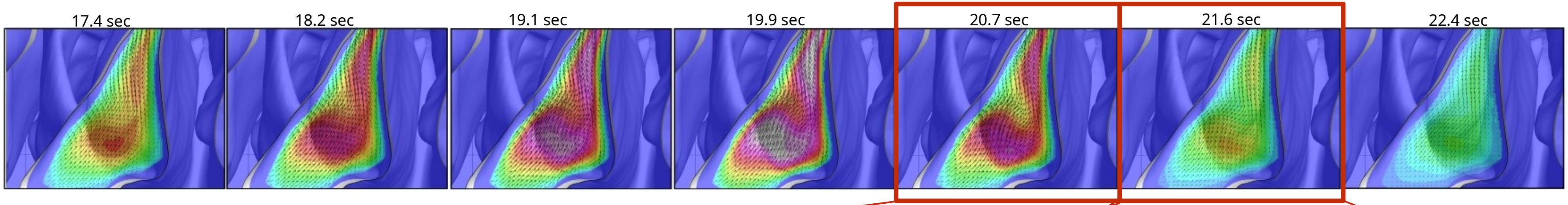


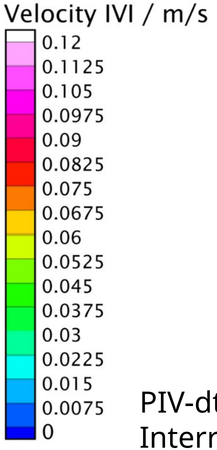
Snapshot of standard deviation of exemplary slice (IVI / m/s)

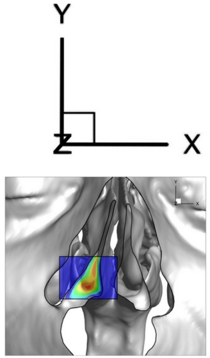


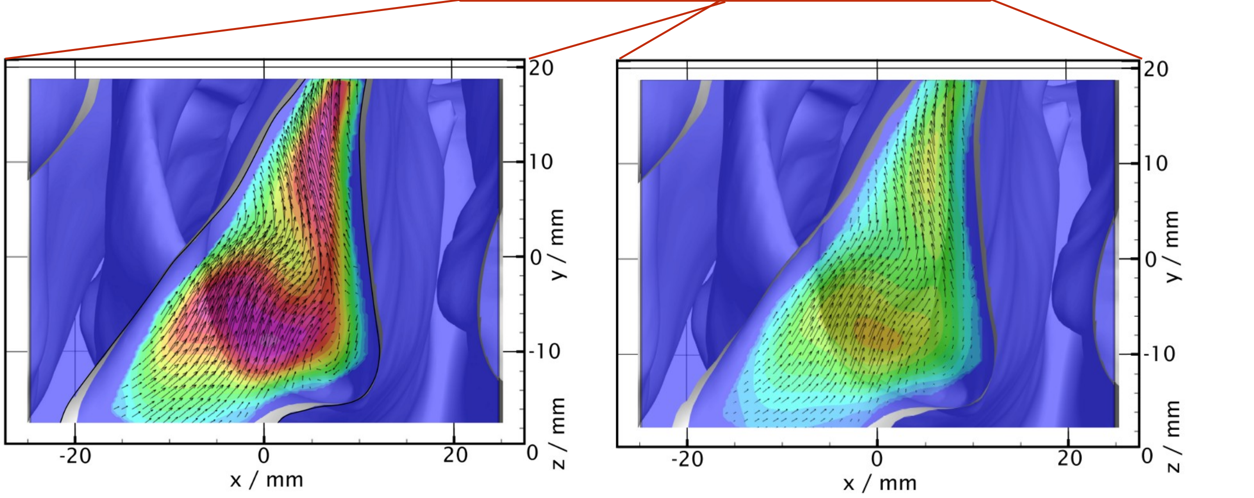
Results - Nostrils











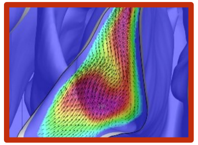
PIV-dt = 7 ms

Interrogation window: 32 vox

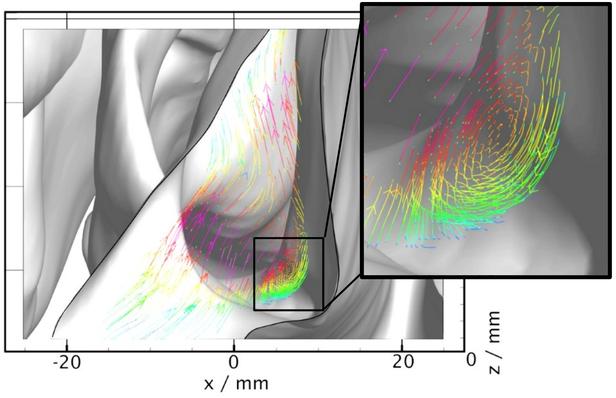
Results - Nostrils

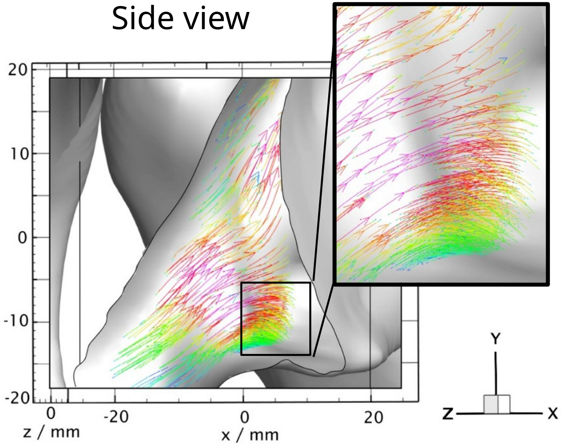
Frontal view

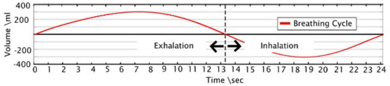
Side view

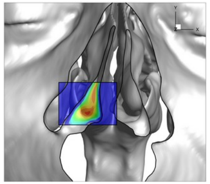


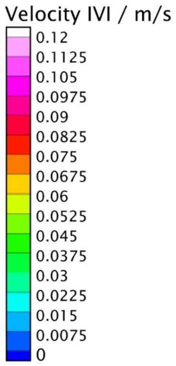
20.7 sec

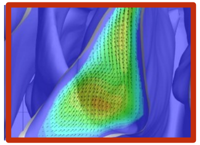




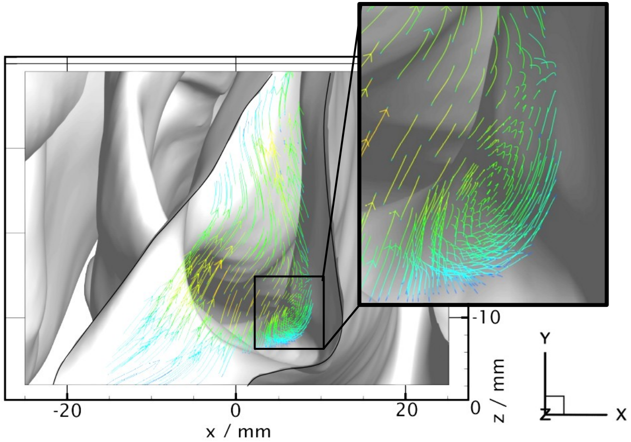


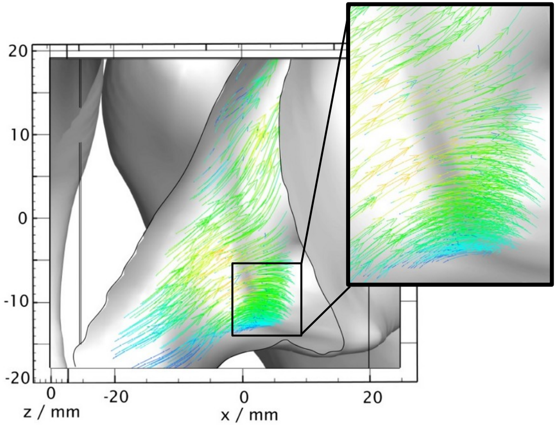






21.6 sec





Conclusion

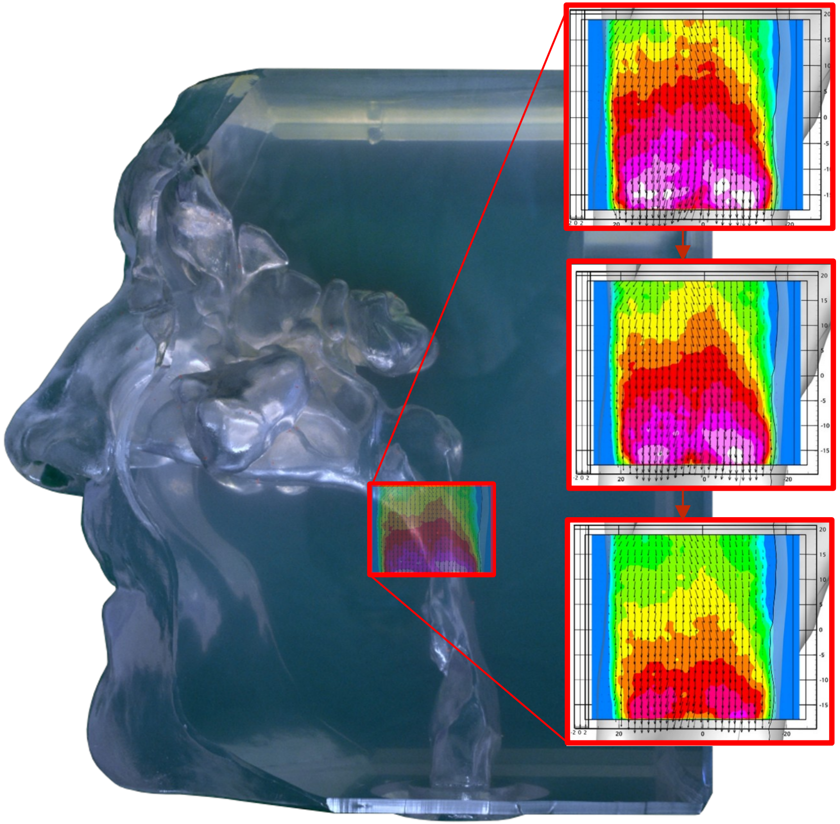
Sucessfull experimental parts:

- **Phantom model development** method enables to build a patient-specific measurement geometry
- **In-site RIM method** minimizes errors and leads to acceptable Volume Self Calibration results
- **Linear-motor-driven-piston pump** gives the possibility to create **physiological flow rates**
- Analysing **different flow rates during cycle** with low-speed setup works while adapting **PIV-dt**
- **Triggered seeding strategy** leads to successful **seeding densities**
- **Tomo-PIV** enables investigations of **complex 3D flow structures**

Outlook

Necessary improvements and further investigations:

- **High-speed system** will allow for a breathing cycle phase dependent PIV-dt
- **Seeding strategy optimization** for low flow regimes (Sinuses)
- Avoid separation of **working fluid's components**
- Enlargement **Field of View** -> Current: Head requires more than 200 RoIs
- Minimize **phase-locked shift** of 120 us



Thank you !

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Acknowledgments
This work is part of the cooperation with Politecnico di Milano and DLR Germany as part of the OpenNOSE project group

Funding
This work is supported by the Bavarian Academic Forum (BayWISS) – Doctoral Consortium “Health Research”, the Regensburg Center of Biomedical Engineering (RCBE), and Regensburg Center of Health Sciences and Technology (RCHST).