Numerical simulation of human nasal cavity flow with particle

V. Covello [‡], C. Pipolo [†], G. Felisati [†], M. Quadrio [‡]

[‡] *Department of Aerospace Science and Technology, Politecnico di Milano, Italy*
[†] *Otorhinolaryngology Unit, S.Paolo Hospital, Università di Milano, Italy*

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CFD of human nasal cavity flow
Challenging and modern topics

Human nasal cavity flow

- complex physical phenomena
  - strong unsteadiness
  - transitional flow
  - complex geometry

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State of Art

- numerical simulation mainly based on the RANS approach
  - favourable computational cost/accuracy ratio for many applications, but wrong results in our context

Objectives

From writing journal papers to improving surgeries

Long term

Improving our understanding on the behaviour of the nasal airflow to assist surgeons on their everyday practice

- **patient-specific surgery planning, and post-surgery analysis**
  $\Rightarrow$ increasing demand for accuracy to capture fine details of the flow

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  - **High-fidelity Large Eddy and Direct Numerical Simulations**

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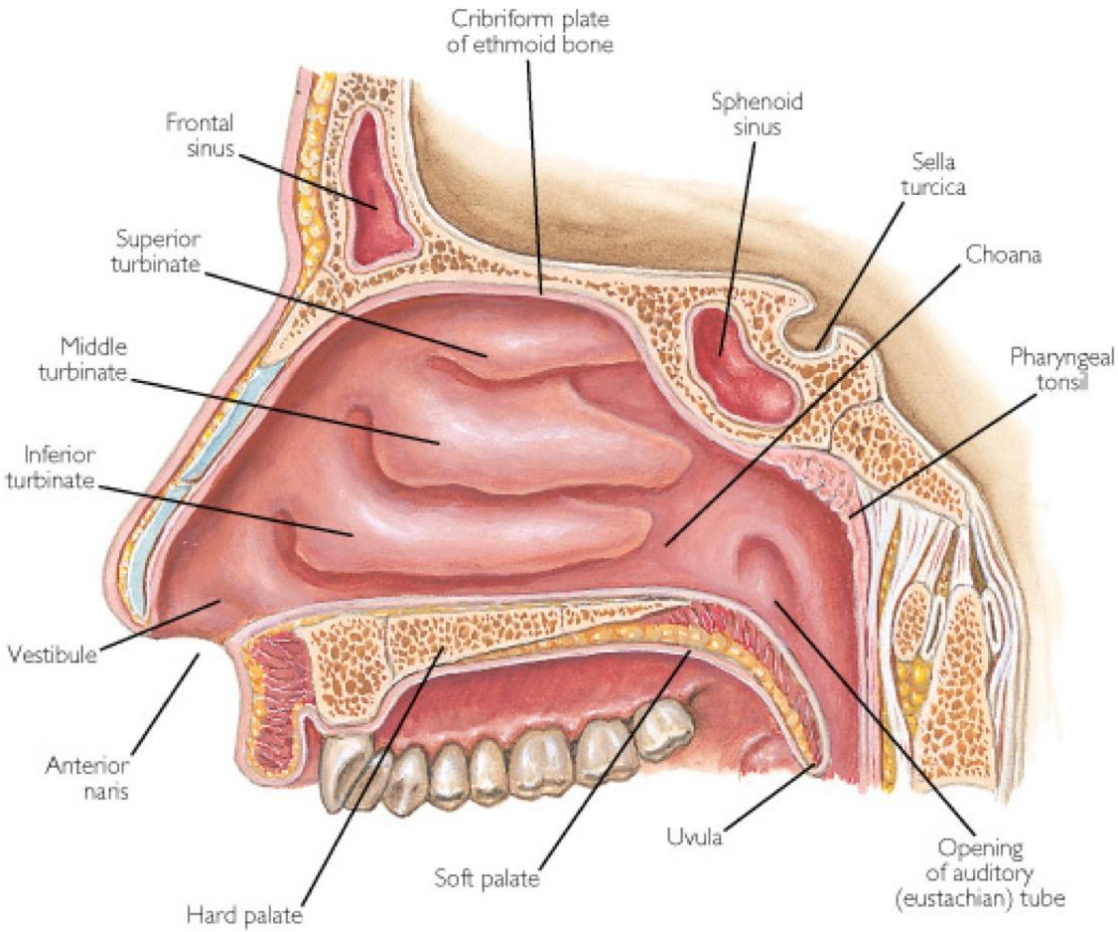
  - **High-fidelity Large Eddy and Direct Numerical Simulations**
  - **development of a robust CFD procedure fully based on open source tools**

Specific

Numerical simulation of thermal water particle delivery for the treatment of inflammatory disorder

Nose anatomy and functionality

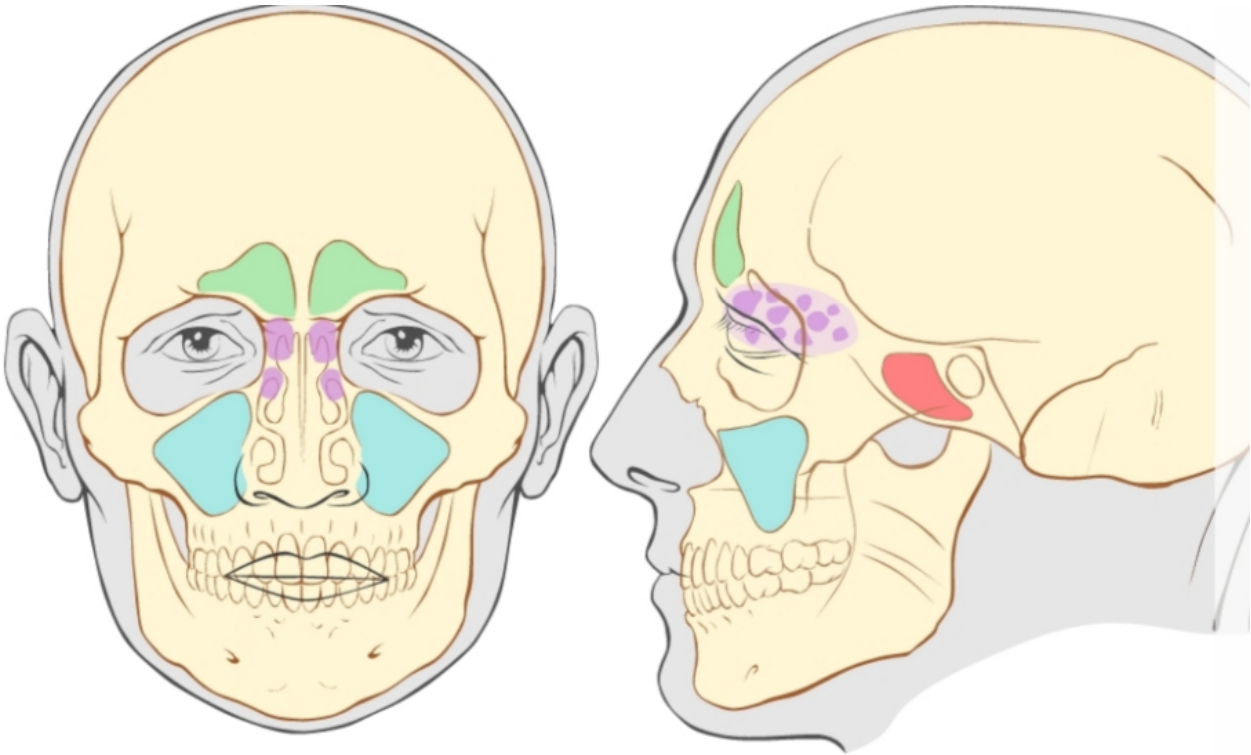
Sagittal view



Nose anatomy and functionality

Paranasal sinuses

Frontal, sphenoid, ethmoidal and maxillary sinuses



Nasal diseases

pathologies and surgical treatment

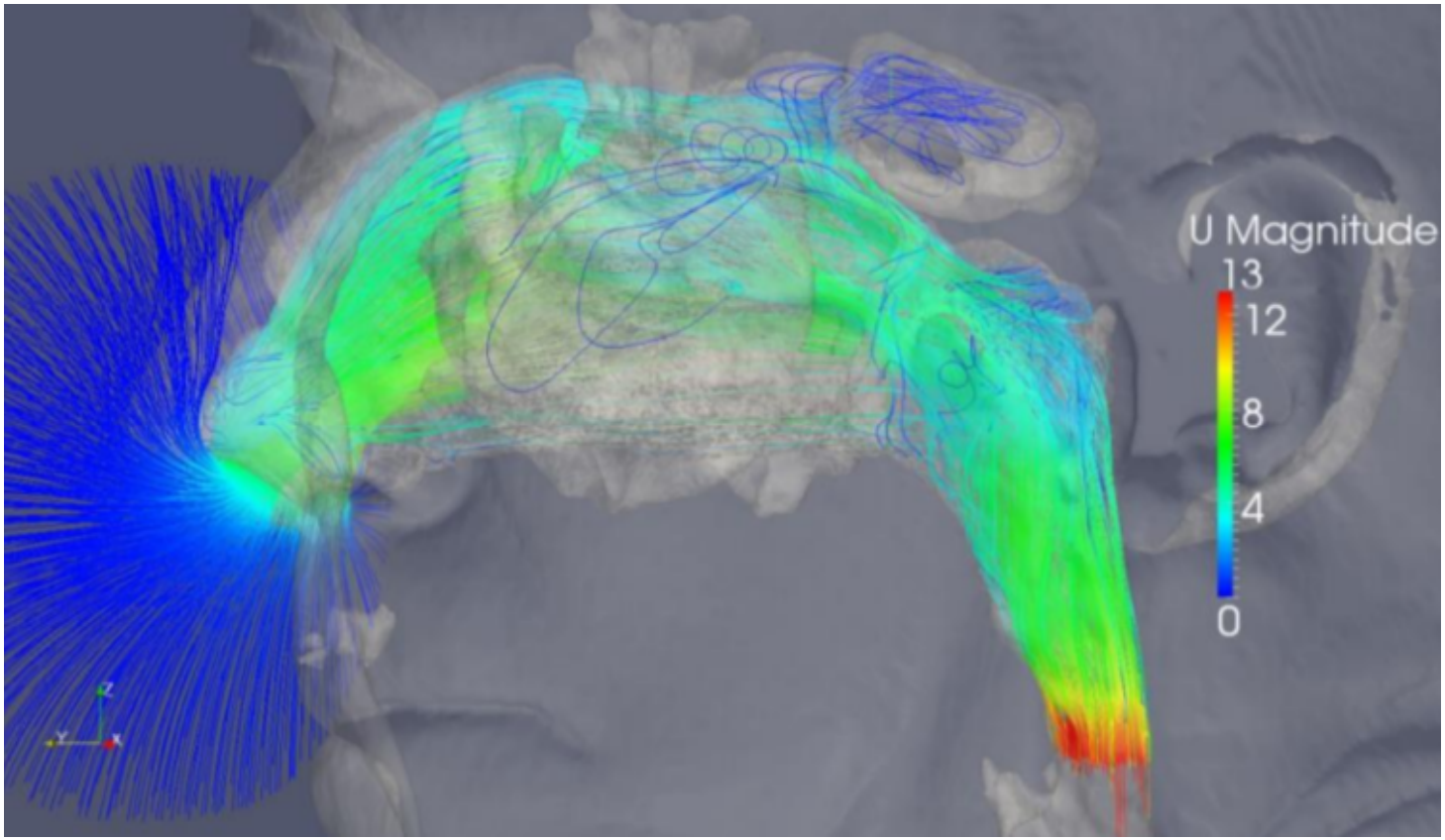
Huge prevalence of

- **rhinosinusitis**
- **nasal obstruction**
- **nasal polyposis**
- **nasal septal deviation ⇒ can only be addressed by surgery**

FESS Functional endoscopic sinus surgery

- **minimally invasive**
- **carried out endoscopically**
- **may involve inferior and/or turbinoplasty and opening the paranasal sinuses**
- **depend on anatomy, specifical clinical condition and surgeon's judgment**

Flow field
Velocity magnitude



Mathematical model

Particles equation - Lagrangian approach

$$\frac{d\mathbf{x}_p}{dt} = u_p,$$

$$m_p \frac{d\mathbf{u}_p}{dt} = \Sigma \mathbf{F}_i$$

$\mathbf{x_p}$ = **position vector**, $\mathbf{u}_p$ = **particles velocity**, m_p = **particles mass**

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Drag force

$$\mathbf{F}_D = \frac{3}{4} \frac{\rho}{\rho_p} \frac{m_p}{d_p} C_D \left(\mathbf{u} - \mathbf{u}_p\right) \left| \mathbf{u} - \mathbf{u}_p \right|$$

Drag coefficient ⊛

$$C_D = \begin{cases} \frac{24}{Re_p}\left(1 + \frac{1}{6} Re_p^{2/3}\right); & Re_p \leq 1000 \\ 0.424; & Re_p \geq 1000 \end{cases}$$

$\mathrm{Re}_p = \rho d_p \left(\mathbf{u}_p - \mathbf{u}\right)/\mu$. **particle Reynolds number**

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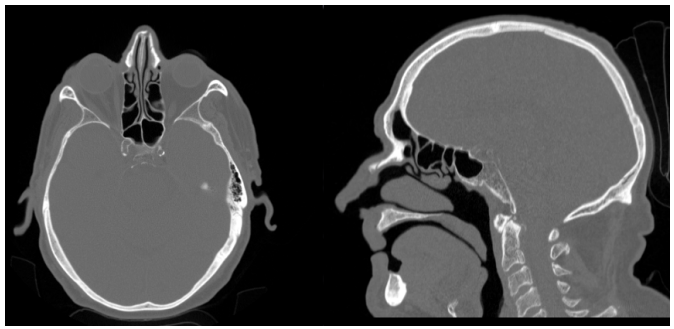
⊛ C.T. Crowe et al. Multiphase flows with droplets and particles. CRC press 2011.

Geometric human nasal cavity model

From the CT scan to the final surface

CT scan data



Reconstruction via the open source software 3DSlicer

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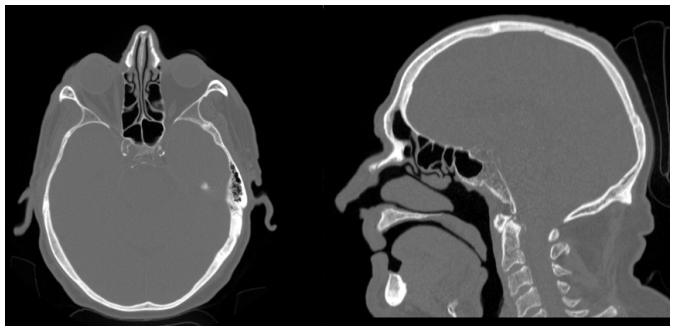

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$$HU = \frac{\mu_x - \mu_{water}}{\mu_{water} - \mu_{air}} * 1000$$

$$HU_{tissue} \approx -220$$

$$HU_{bones} \approx 400$$

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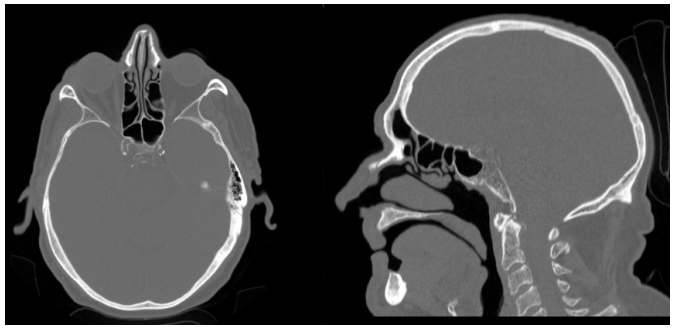

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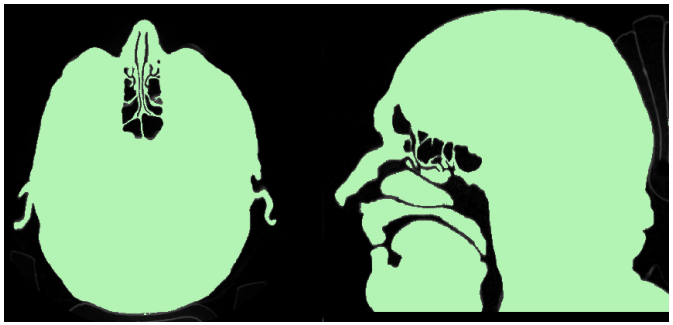

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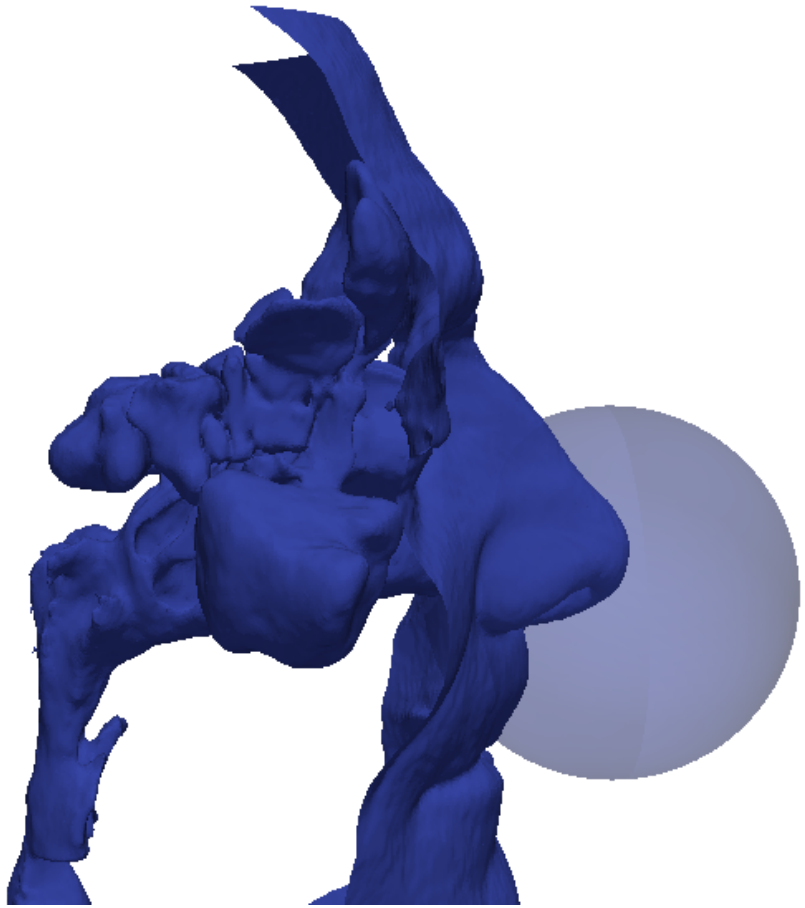
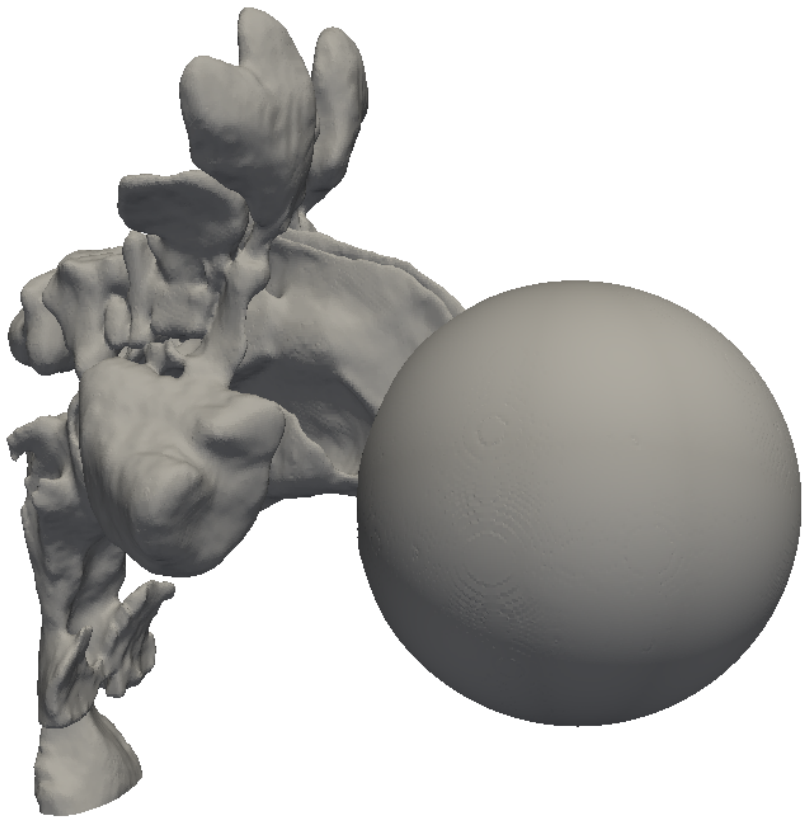
Stl model



Numerical Results

Steady inspiration with water particles

Computational domain



Δp =20 Pa,
Q = 20 L/min
N = 10^6 particles
D = 5, 10, 50 μm
Aerosol,
Inhalation,
Atomized Nasal Douche

mesh ⇒ 1 to 25Mil of cells

OpenFOAM
one-way couplig
⇒ icoUncoupledKinematicCloud

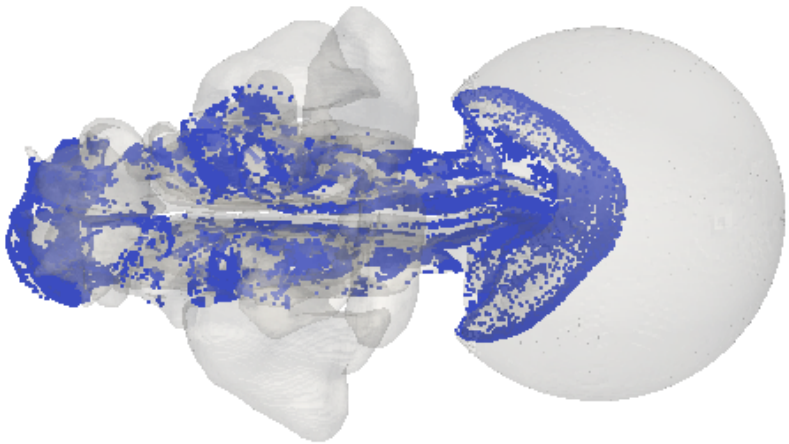
Galileo cluster CINECA

Numerical Results

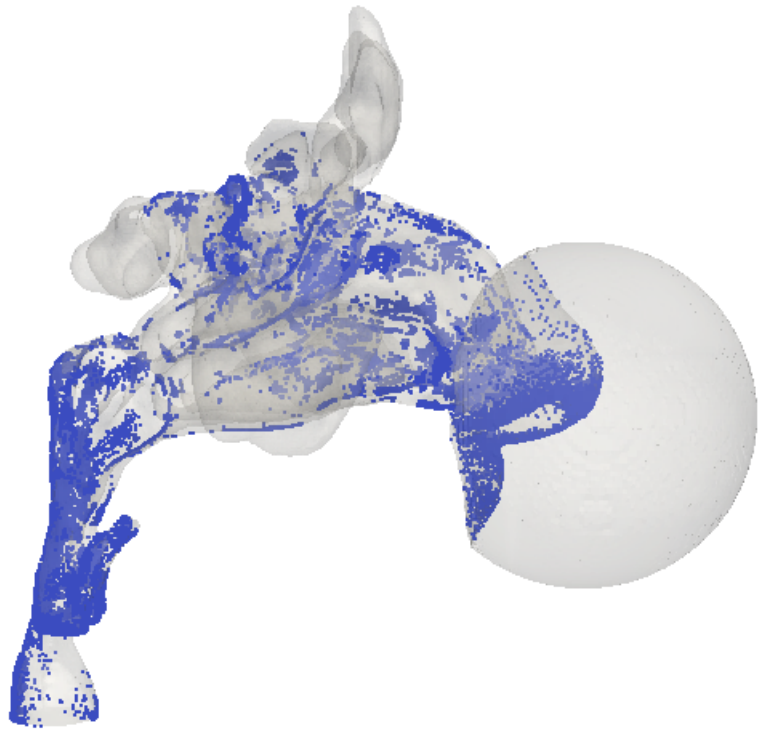
Steady inspiration with water particles

particle deposition T=0.6 sec, D= 5 μm, Aerosol

Top view



Side view



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Steady inspiration with water particles

particle deposition T=0.6 sec, D= 10 μm, Inhalation

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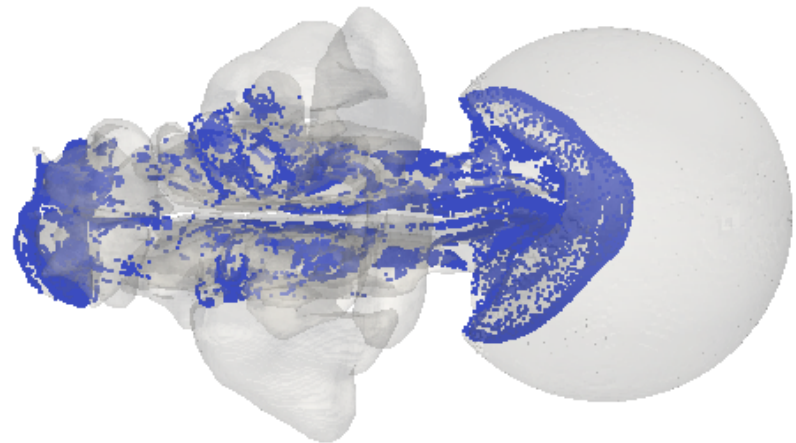

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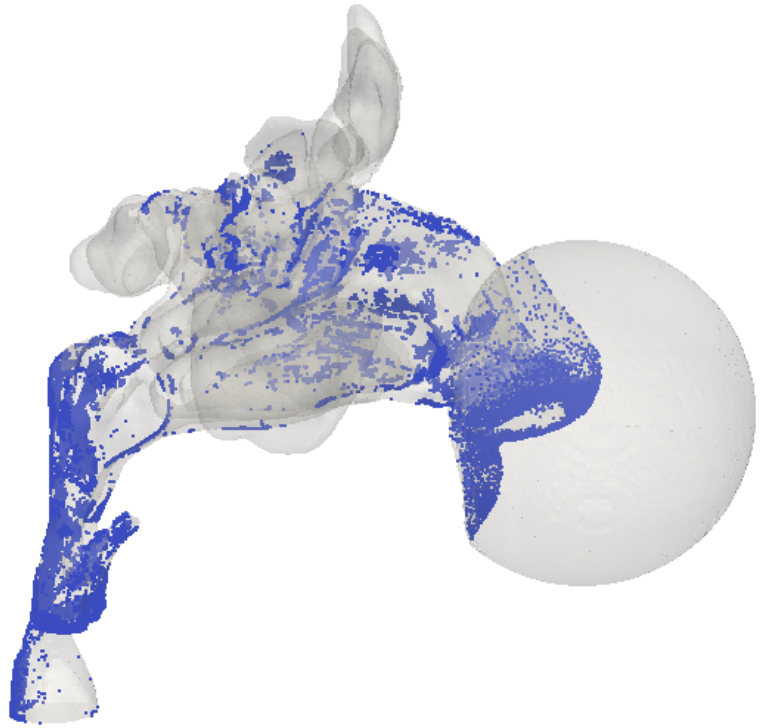
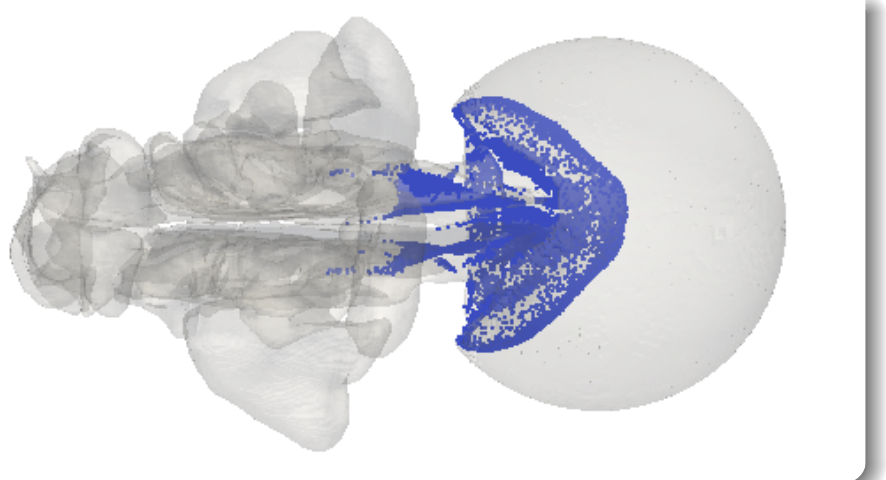


Numerical Results

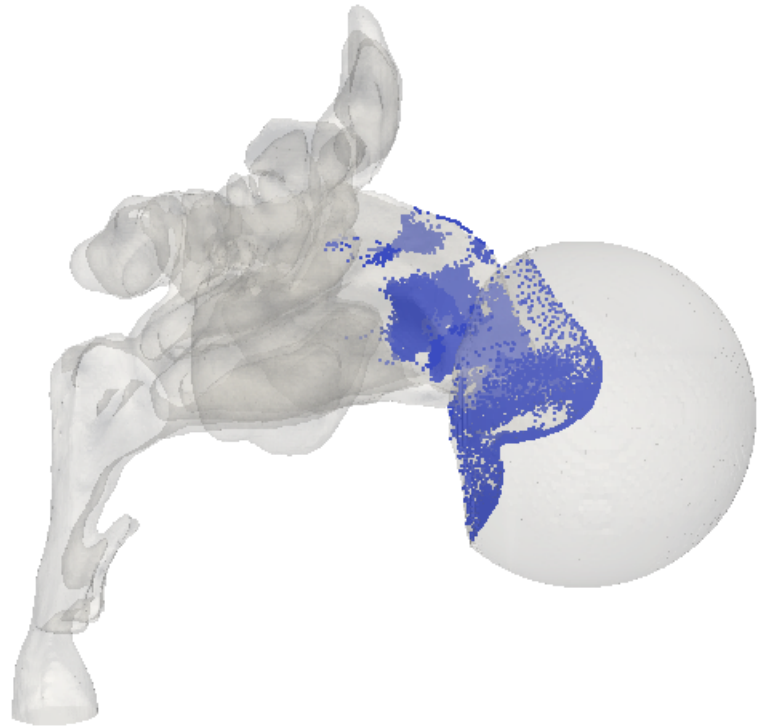
Steady inspiration with water particles

particle deposition T=0.6 sec, D= 50 μm, Atomized Nasal Douche

Top view



Side view

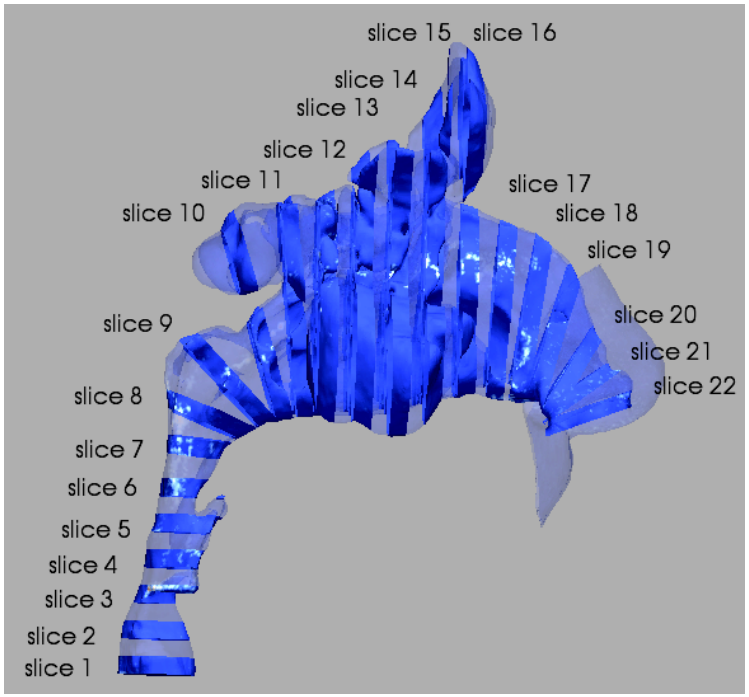


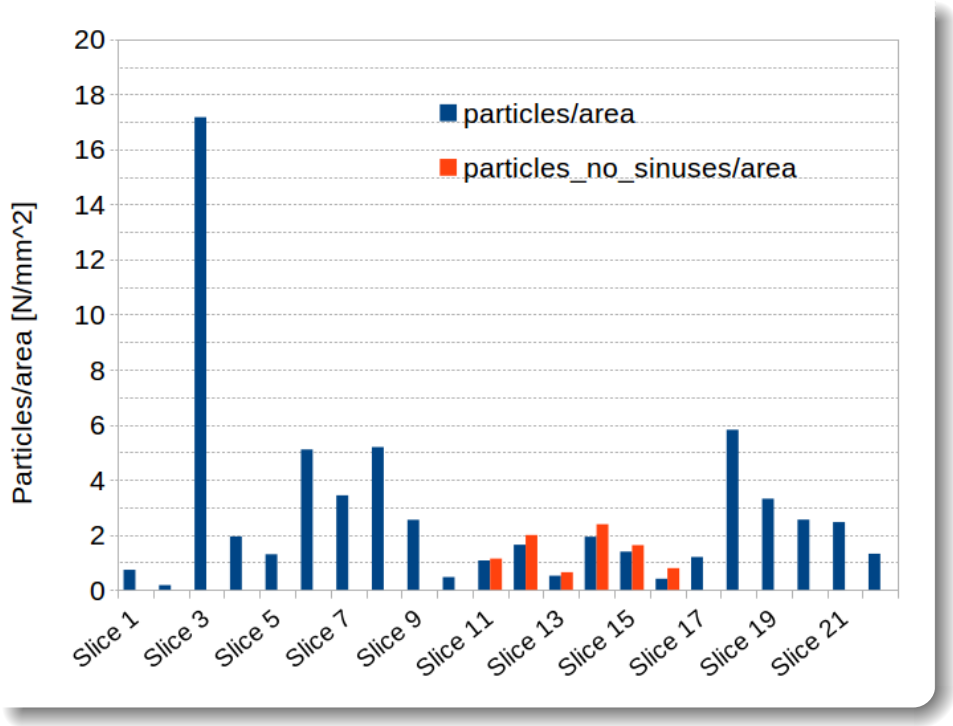
Numerical Results

Steady inspiration with water particles

particle deposition after 0.6 sec, D= 5 μm, Aerosol

Quantitative analysis - Particles/area





Conclusion

Improving our understanding on the thermal water delivery for the treatment of inflammatory disorder in the human nasal cavity.

- **Aerosol, Inhalation, Atomized Nasal Douche**

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- realistic computational domain

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Ongoing work and Future developments

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Ongoing work and Future developments

- quantitative evaluation of the deposition efficiency

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- mesh sensitivity
- pollutant transport

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Thank you