

The nose

Our *vision*

The  
procedure

Validation?

The future

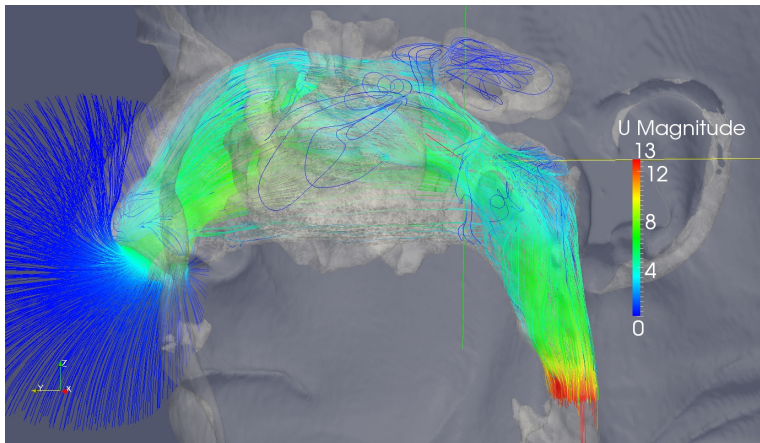
# FLUID DYNAMICS OF THE NASAL CAVITY: HOW TO, WHAT FOR.

Maurizio Quadrio

Politecnico di Milano  
Dept. of Aerospace Sciences and Technologies

Roma, Jan 20, 2015

- The nose
- Our *vision*
- The procedure
- Validation?
- The future



# CREDITS

MINISTERO DELLA SALUTE, CINECA

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## S.PAOLO & UNIMI

- Giovanni Felisati
- Carlotta Pipolo
- Francesco Messina
- Alberto Saibene

## POLIMI

- Stefano Corti, Samuele Zampini, Chiara Pesci, Eleonora Biondi, Giacomo Lamberti, Francesco Manara
- Simone Raina
- Fabio Cozzi
- Franco Auteri
- Marco Belan

# OUTLINE

The nose

*Our vision*

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The future

**1** THE NOSE

**2** *OUR vision*

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**4** VALIDATION?

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# FUNCTIONS OF THE HUMAN NOSE

## FIRST (UPPER) PART OF RESPIRATORY AIRWAYS

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Many functions!

- Air filtering
- Air humidification
- Air heating / cooling
- Olfaction (+ taste!)

# INTERNAL STRUCTURE

The nose

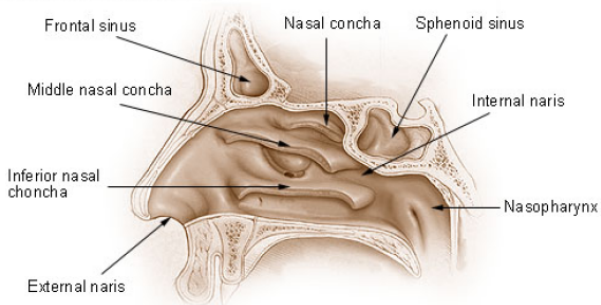
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The procedure

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## Nose and Nasal Cavities



# SINUSES AND TURBINATES

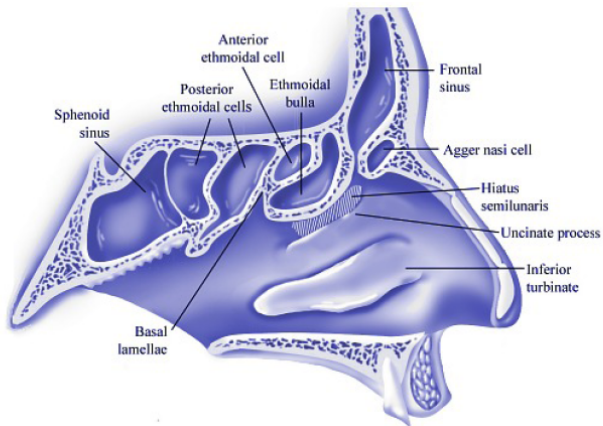
The nose

Our vision

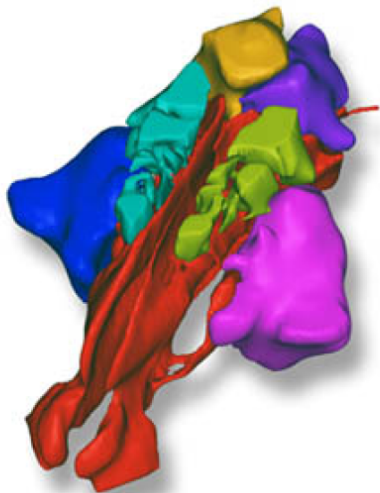
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# A 3D VIEW



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# CORONAL SECTION: TURBINATES AND MEATA

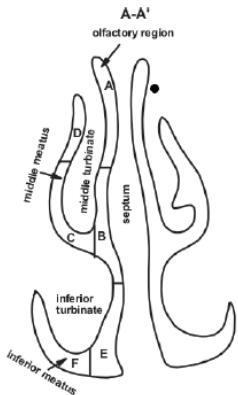
The nose

Our vision

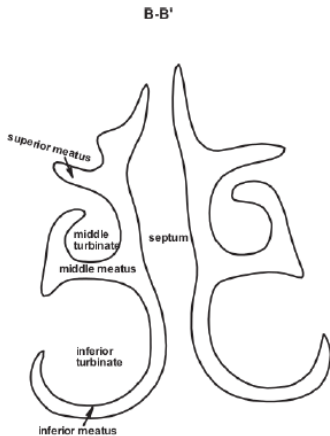
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- A: Olfactory region
- B: Main passageway below middle meatus
- C: Lower middle meatus region
- D: Deep middle meatus region
- E: Main passageway below inferior meatus
- F: Inferior meatus



# SIGNIFICANT LONGITUDINAL VARIATIONS

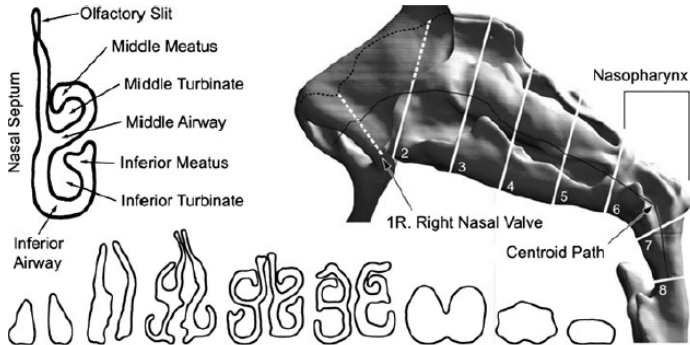
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# HOW TO STUDY THE NASAL CAVITY

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The future

- *In-vivo* approach: difficult, not useful
- *In-vitro* approach: rarely used
- First meaningful CFD study in 2004 (Zhao, Chem. Senses)

# CFD: STATE OF THE ART

## CHARACTERISTICS AND LIMITATIONS

The nose

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The future

- Long times (weeks/months) for producing a mesh
- Questionable (but never questioned!) modellistic approaches
- RANS (or laminar)
- Results are not validated

# OUTLINE

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**1** THE NOSE

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# THE PROBLEM

NBD HAVE A LARGE SOCIAL/ECONOMICAL IMPACT

The nose

**Our vision**

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In 2009 Regione Lombardia has spent:

- Septoplastic: 5600 procedures, 8.6M€
- Turbinates surgery: 3000 procedures, 4.3M€
- FESS: 5700 procedures, 11.6M€

# FESS

## ENDOSCOPIC SURGICAL RESTORATION OF LEFT NOSE

The nose

**Our vision**

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Validation?

The future



# THE STATE OF THE ART

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*Nowadays functional endoscopic sinus surgery (FESS) is the gold standard for chronic NBD treatment. The operation generally involves inferior/middle turbinoplasty and uncinata and ethmoid excision, sometimes followed by opening of the maxillary, sphenoid and frontal sinuses. A correction of a nasal septal deviation can also be necessary.*

...

*However, we are currently unable to assess the relevance of every single anatomic anomaly and its surgical modification on the overall nasal flow quality and nasal obstruction.*

Quadrio et al, Eur. Arch. Oto-Rhino-Laryngology Head Neck, 2014



# OUTLINE

**1** THE NOSE

**2** OUR *vision*

**3** THE PROCEDURE

**4** VALIDATION?

**5** THE FUTURE

The nose

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procedure**

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# THE PROCEDURE

The nose

Our vision

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Validation?

The future

- *Patient-specific* procedure
- CFD results from a CT scan
- Virtual surgery
- **Reliable** results
- Robust and feasible procedure (**time** and **cost**)
- Goal: support / reduce / optimize surgery

# THE TOOLCHAIN

The nose

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**The  
procedure**

Validation?

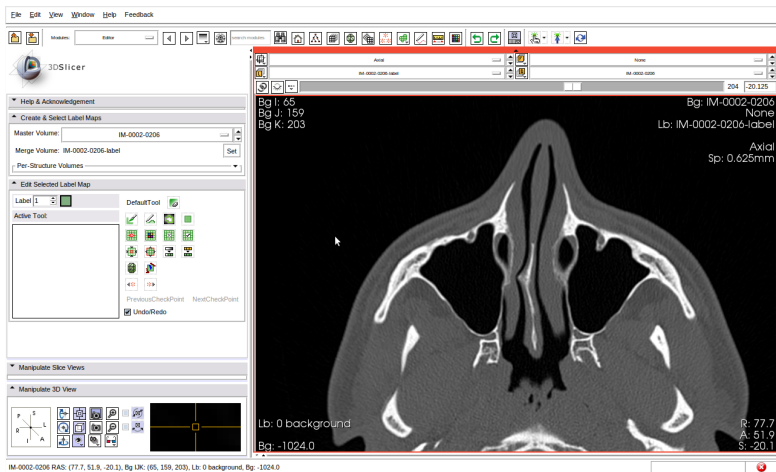
The future

- 1** Analysis of CT scan (3DSlicer)
- 2** STL from CT scan (3DSlicer)
- 3** Volume mesh (OpenFOAM – snappyHexMesh)
- 4** CFD (OpenFOAM)

# 1/4 ANALYSIS OF THE CT SCAN

## IMPORTANT SEPTAL DEVIATION

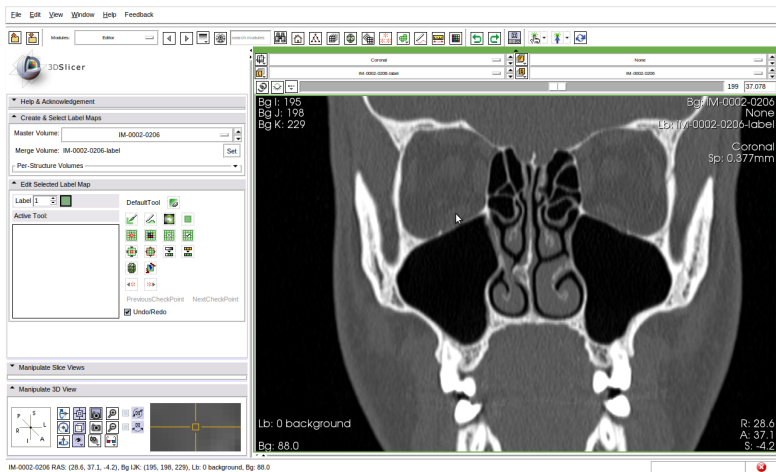
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# 1/4 ANALYSIS OF THE CT SCAN (2)

## NEARLY-COMPLETE OBSTRUCTION

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The procedure  
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2/4

# STL FROM CT SCAN

WRONG HU THRESHOLD

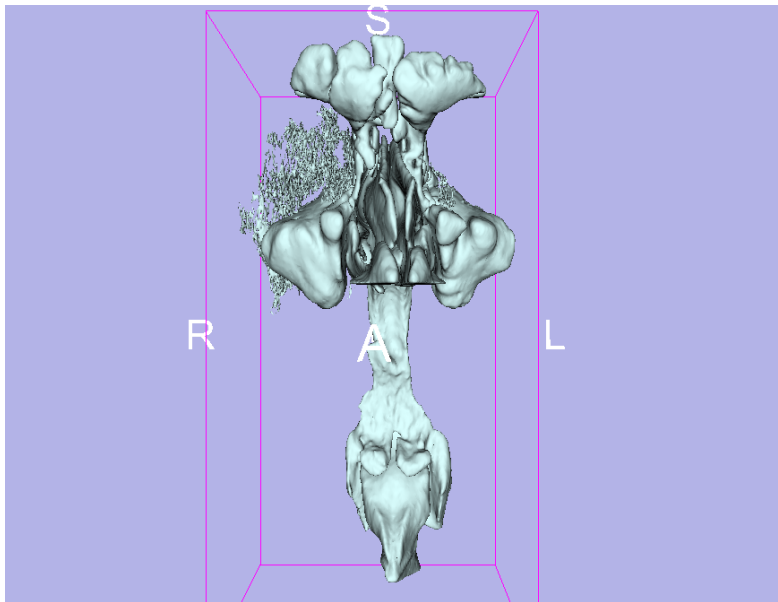
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**The procedure**

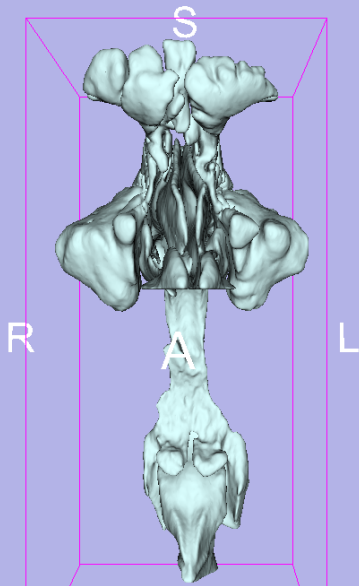
Validation?

The future



## 2/4 STL FROM CT SCAN (2)

CORRECT HU THRESHOLD



The nose

Our vision

**The procedure**

Validation?

The future

# 3/4 VOLUME MESH

## CASTELLATED MESH

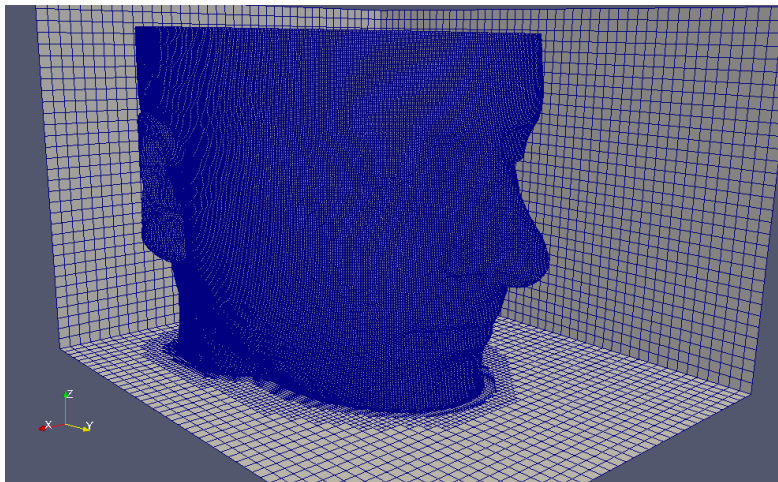
The nose

Our *vision*

**The  
procedure**

Validation?

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# 3/4 VOLUME MESH (2)

## CASTELLATED MESH

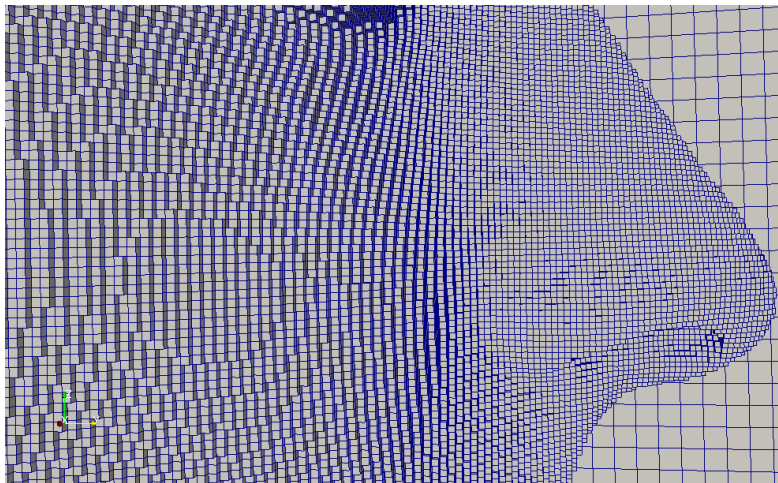
The nose

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**The procedure**

Validation?

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3/4  
SNAP

# VOLUME MESH (3)

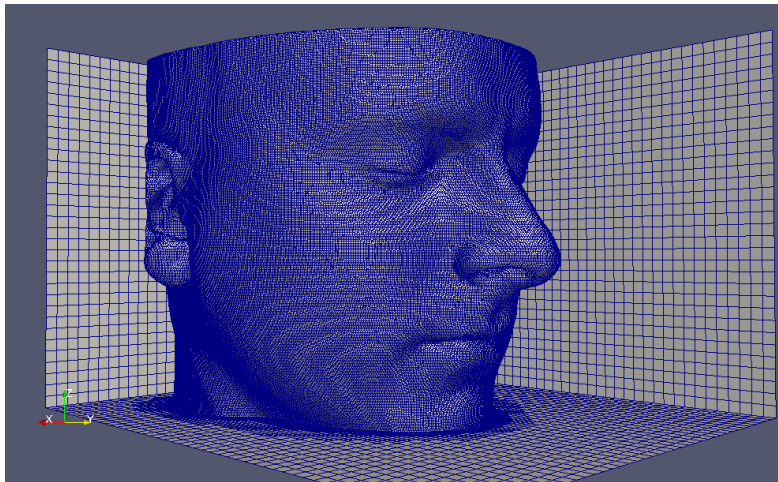
The nose

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3/4

## VOLUME MESH (4)

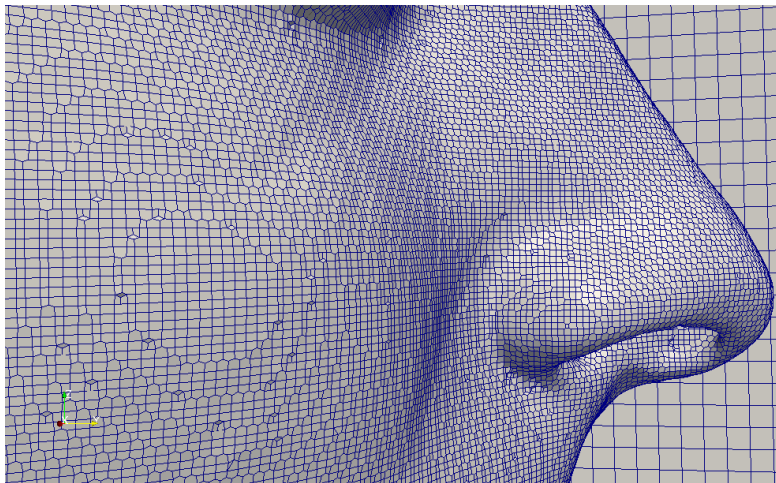
The nose

Our *vision*

**The  
procedure**

Validation?

The future



# 3/4 VOLUME MESH (6)

## MESH REFINEMENT

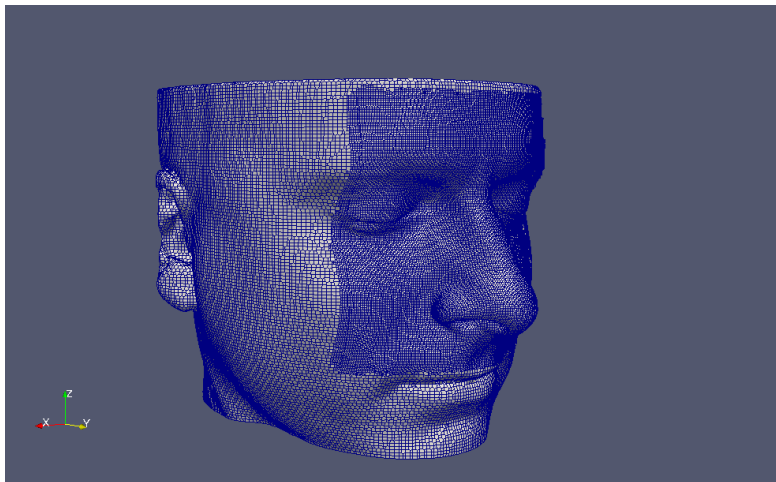
The nose

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# 3/4 VOLUME MESH (6)

## MESH REFINEMENT

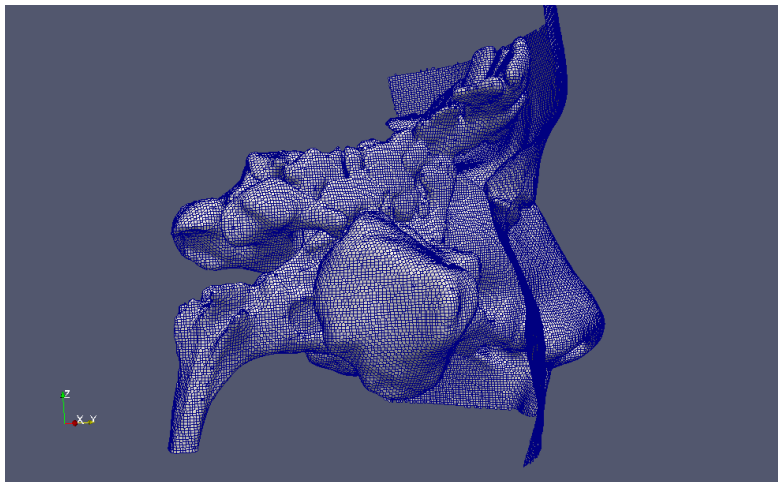
The nose

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Validation?

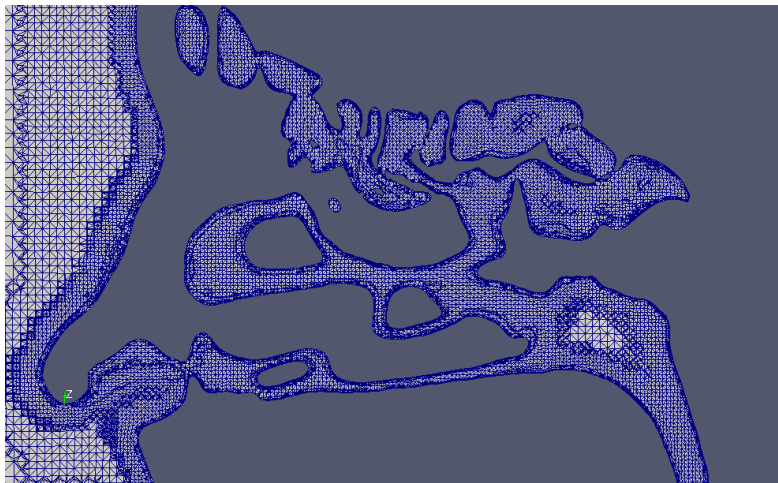
The future



# 3/4 VOLUME MESH (7)

ADDING LAYERS

- The nose
- Our vision*
- The procedure**
- Validation?
- The future

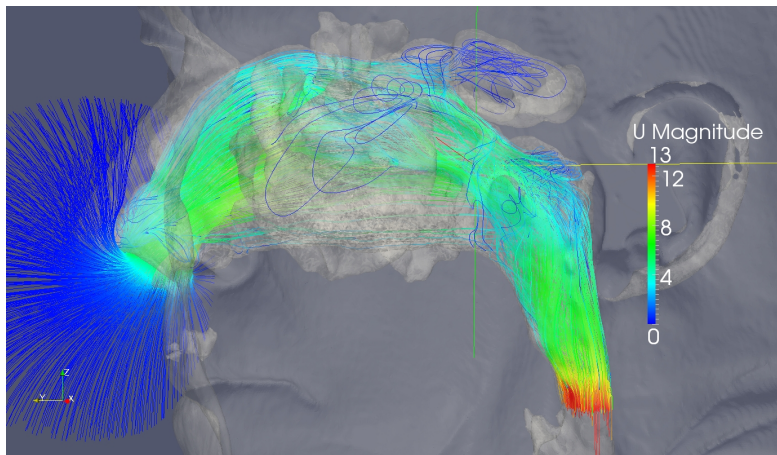


4/4

CFD

STEADY INSPIRATION, LAMINAR

- The nose
- Our vision
- The procedure**
- Validation?
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# VIRTUAL SURGERY

## REMOVING SEPTAL DEVIATION / TURBINATE REDUCTION

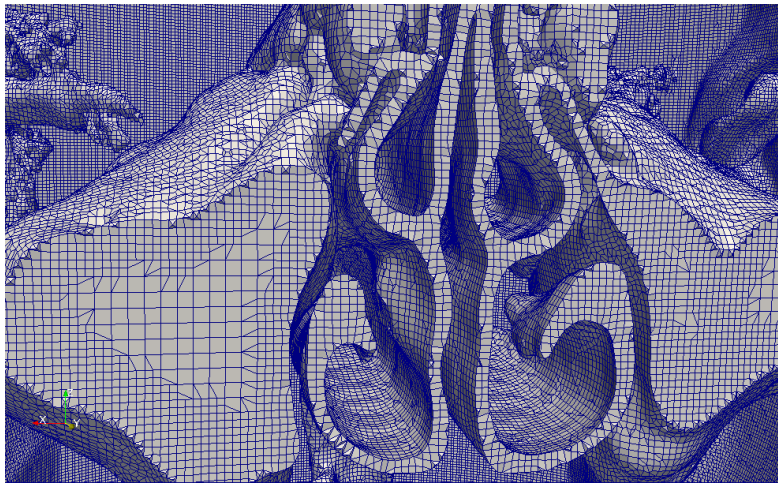
The nose

*Our vision*

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Validation?

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# VIRTUAL SURGERY (2)

## PRE-POST SURGERY COMPARISON, CORONAL VIEW

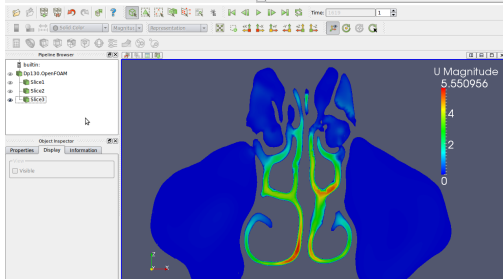
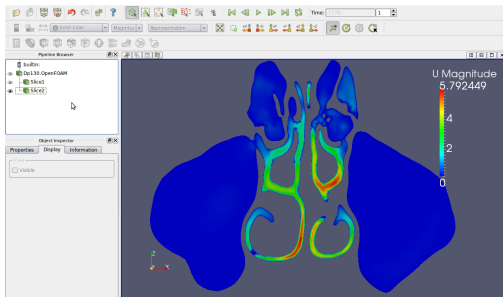
The nose

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# VIRTUAL SURGERY (3)

## PRE-POST SURGERY COMPARISON, AXIAL VIEW

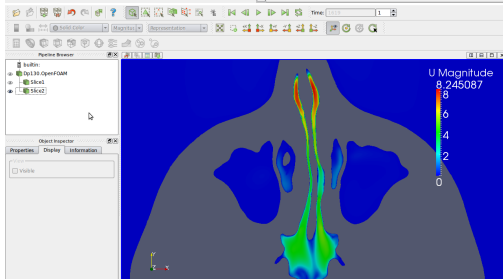
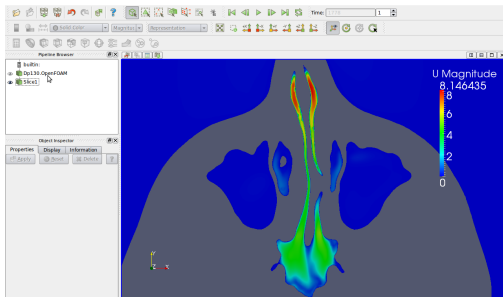
The nose

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# OUTLINE

The nose  
Our *vision*  
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**Validation?**  
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**5** THE FUTURE

# WHAT WE ARE DOING NOW

TOWARDS AN OPEN-SOURCE COMPLETE DATASET

The nose

Our *vision*

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procedure

Validation?

The future

A **PIV experiment** is being designed:

- help choosing the numerical approach(es)
- help validating the numerical tool(s)
- distribute the dataset freely and make it a benchmark

A **DNS/LES database** is being built for cross-validation

# QDNS/LES

The nose

Our *vision*

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procedure

**Validation?**

The future

## MOVIE

# WHICH BOUNDARY CONDITION(S)?

## STEADY INSPIRATION

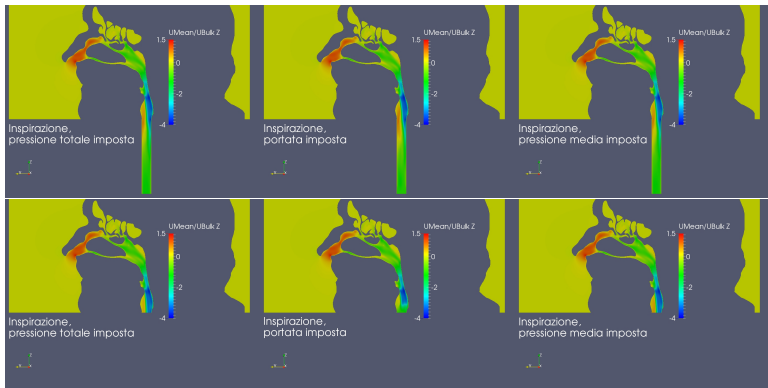
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# WHICH BOUNDARY CONDITION(S)?

## STEADY EXPIRATION

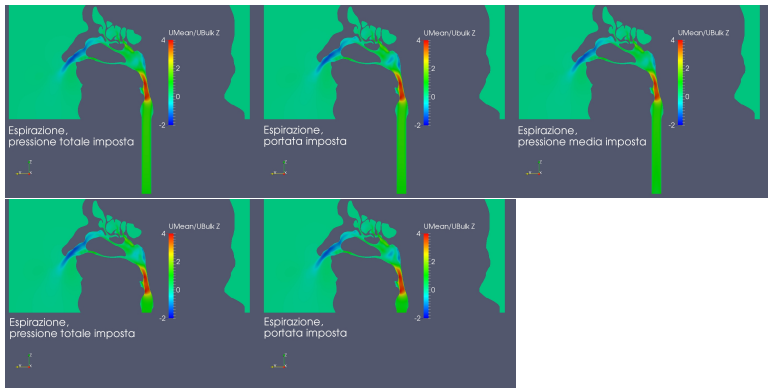
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# 2D-3C PIV VELOCITY MEASUREMENTS

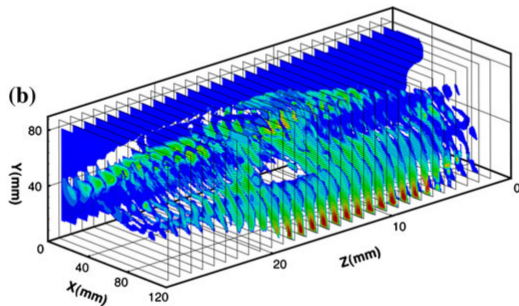
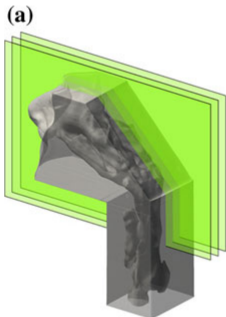
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# THE TANK

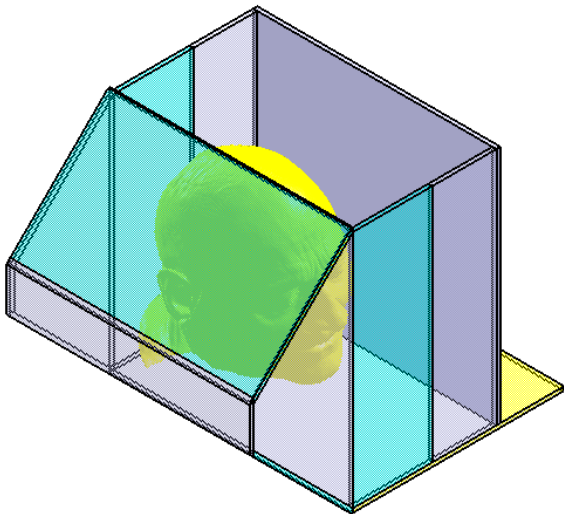
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**Validation?**

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# MEASUREMENT STRATEGY

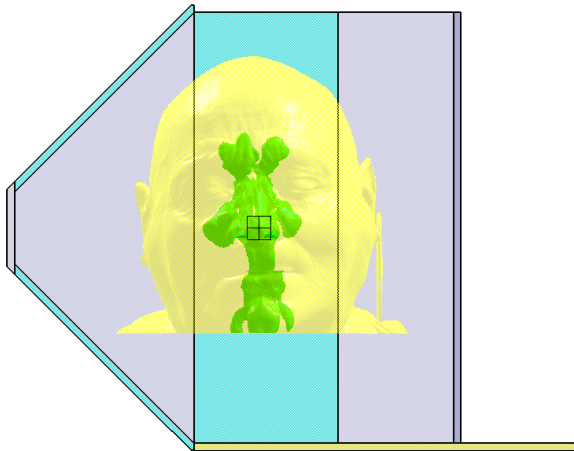
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**Validation?**

The future



# HOW TO BREATHE

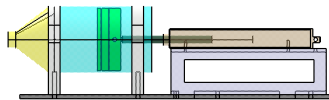
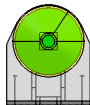
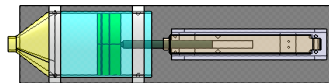
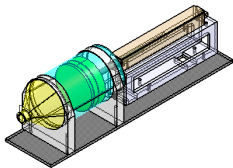
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# A LONG EXPERIMENT...

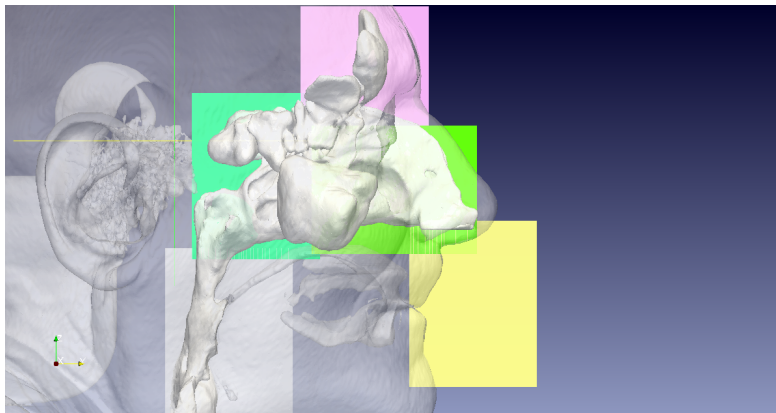
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# BUILDING THE MODEL

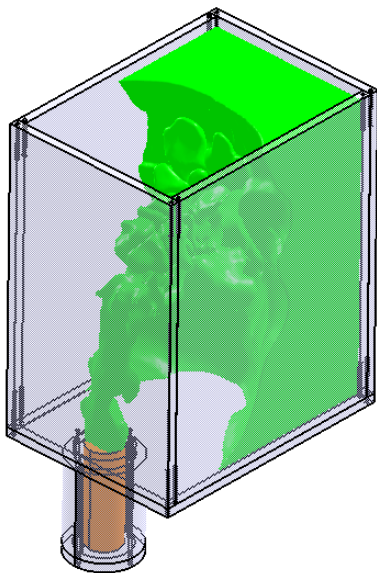
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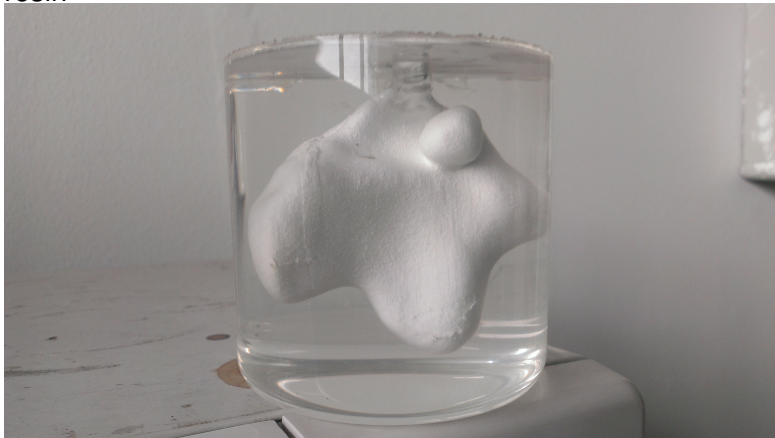
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# THE PHANTOM MODEL

1) Dissoluble material coated and embedded in silicone resin



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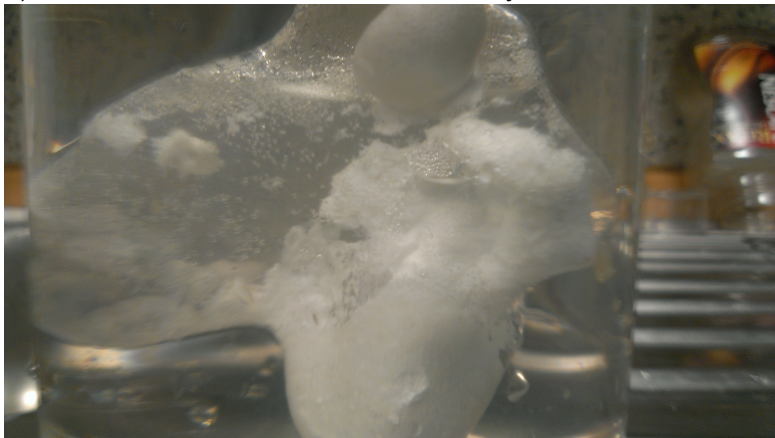
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# THE PHANTOM MODEL

## 2) Removal of the dissoluble material by water



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**Validation?**

The future

# THE PHANTOM MODEL

3) Filled with water + glycerine: the model is... phantom!



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# OUTLINE

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# NEXT STEPS

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Validation?

The future

- Succeed with the experiment
- Further refine Hi-Fi modeling (LES and DNS)
- Promotion, larger-scale deployment and clinical trial
- Every optimization needs an objective function!

# THE ROLE OF OPENFOAM AND OPENSOURCE

The nose

Our *vision*

The  
procedure

Validation?

**The future**

- Open: free
- Open: reliable
- Open: flexible