



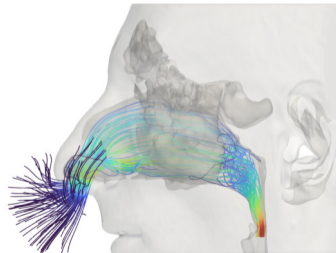
POLITECNICO
MILANO 1863

DIPARTIMENTO DI SCIENZE
E TECNOLOGIE AEROSPAZIALI

Computational Fluid Dynamics in rhinology (a personal view)

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Otorhinolaryngology – Head and Neck Surgery Society
Autumn Training Days, Tampere, Oct 9th, 2025



The nose flow

- ▶ At least 1/3 of the adult world population is troubled with nasal breathing difficulties¹
- ▶ In 2014, the one-year (only) cost of cronic rhinosinusits (alone) in US (only) was \$22bn²
- ▶ Certain nose surgeries have 50% – 80% failure rate³

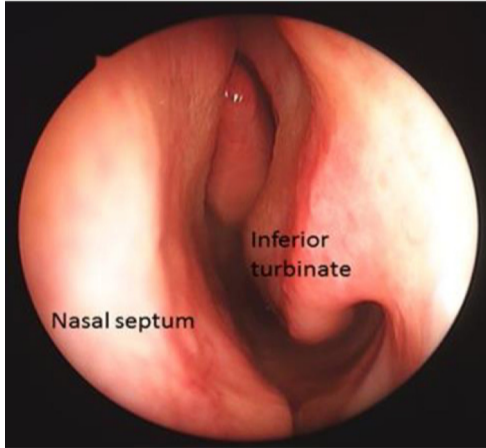
Huge **room for improvement!**

¹Stewart *et al.* Int J Gen Med 2010

²Smith *et al.* The Laryngoscope 2015

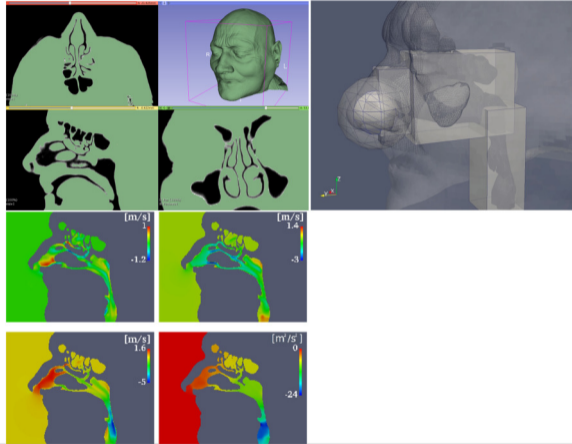
³Sundh & Sonnergreen, Eur Arch Otholaringol 2015

Form and function



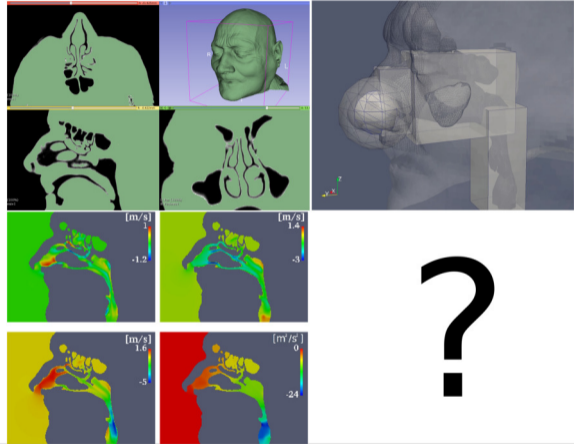
Adding flow field information with CFD

1. Segment the CT scan
2. Build a volume mesh
3. Compute a CFD solution



Adding flow field information with CFD

1. Segment the CT scan
2. Build a volume mesh
3. Compute a CFD solution
4. Then what??



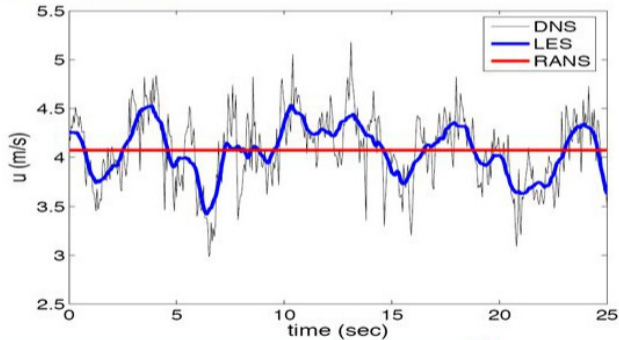
The lack of the **functionally normal** nose

- ▶ Link between form and function is mediated by the **highly non-linear** Navier–Stokes equations
- ▶ Shape **optimization** problem, but **objective function** is unknown
- ▶ Bottom line: in rhinology, CFD by itself is useless

What is CFD?

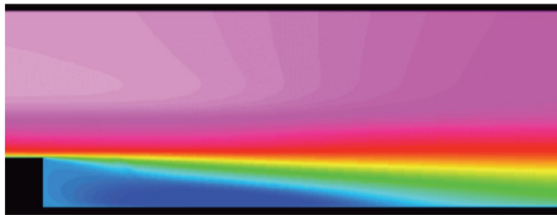
Not all CFDs are made equal

- ▶ **High-fidelity** vs low-fidelity CFD
- ▶ **Time-resolved** vs time-averaged CFD

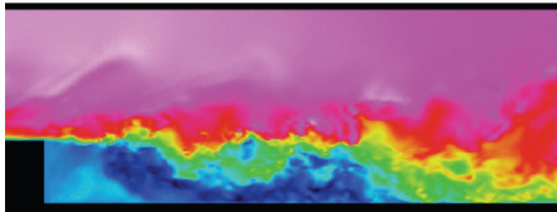


Important differences!

Low-fidelity,
time-averaged CFD

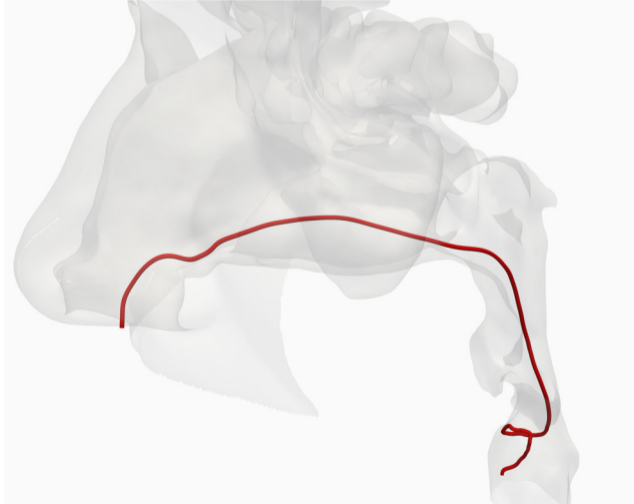


High-fidelity,
time-resolved CFD



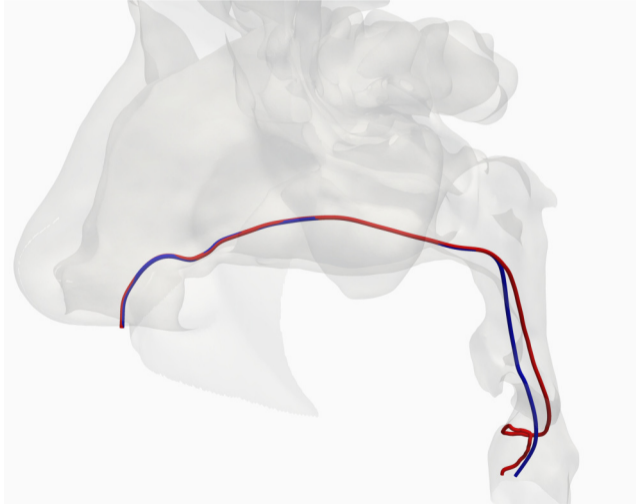
The nose flow

DNS snapshot



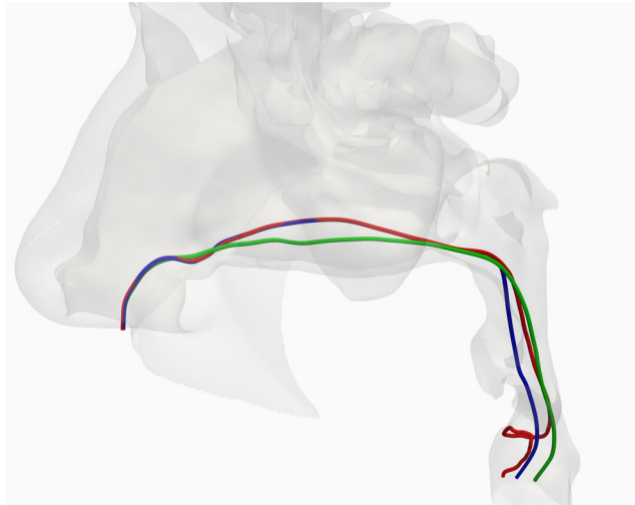
The nose flow

DNS snapshot, time average



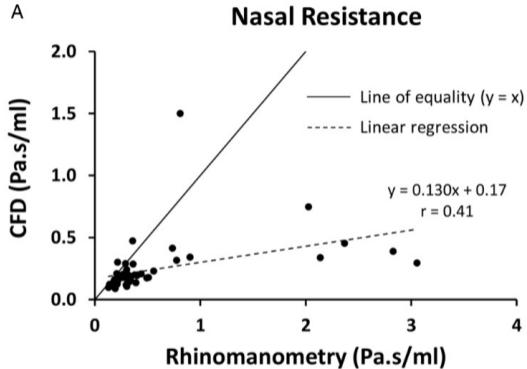
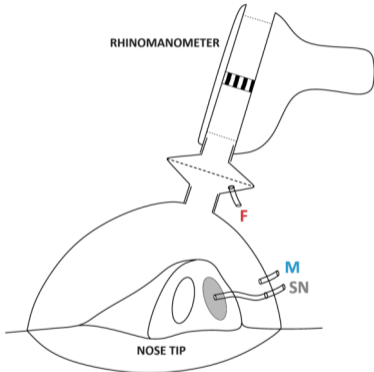
The nose flow

DNS snapshot, time average, RANS



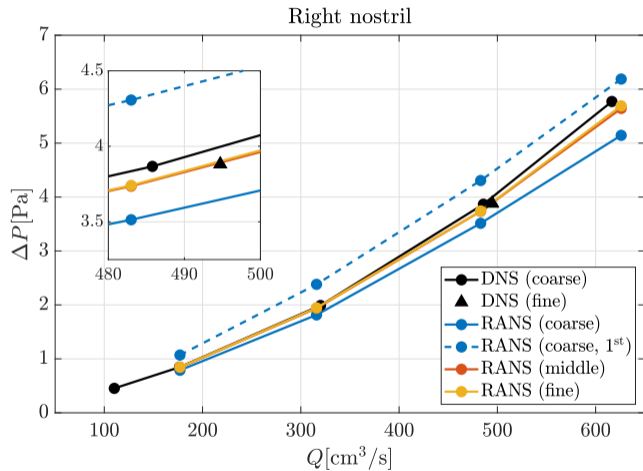
A CFD success story: rhinomanometry

CFD does not replicate clinical rhinomanometry

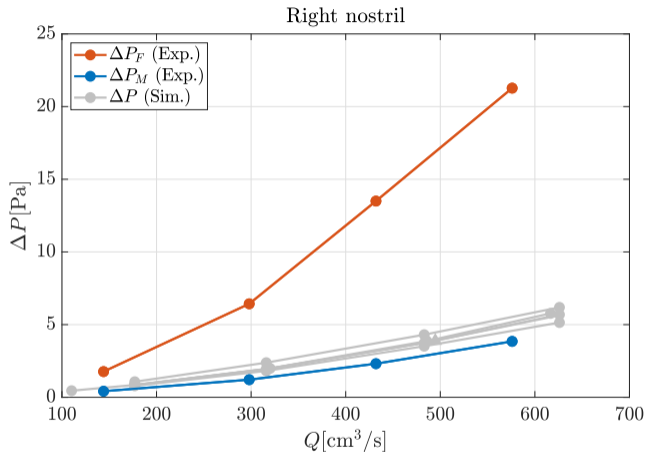
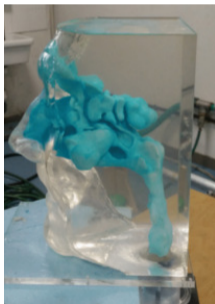


Cherobin et al, "Rhinomanometry Versus Computational Fluid Dynamics: Correlated, but Different Techniques," *Am J Rhinol Allergy*, vol. 35, no. 2, pp. 245–255, Aug. 2020, <http://doi.org//10.1177/1945892420950157>

CFD is self-consistent...



...but the clinical device is way off...



...unless the **ambient pressure** is measured properly!

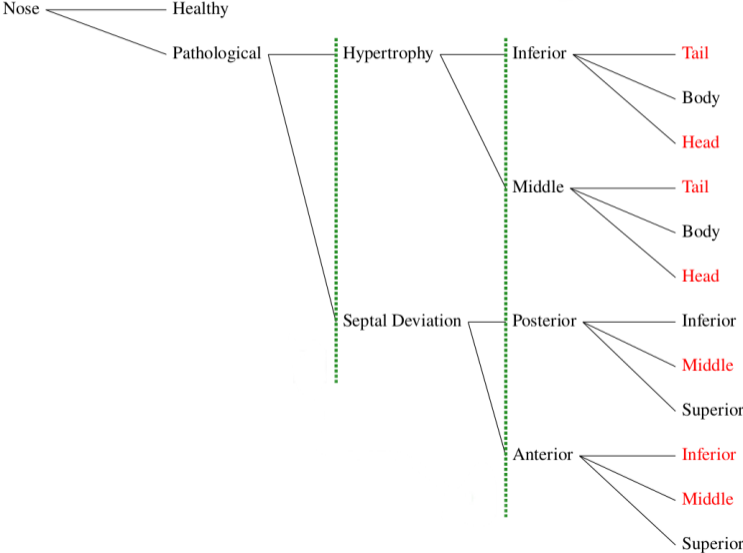
AI in Rhinology, with CFD

Can AI/ML inform surgical decisions?

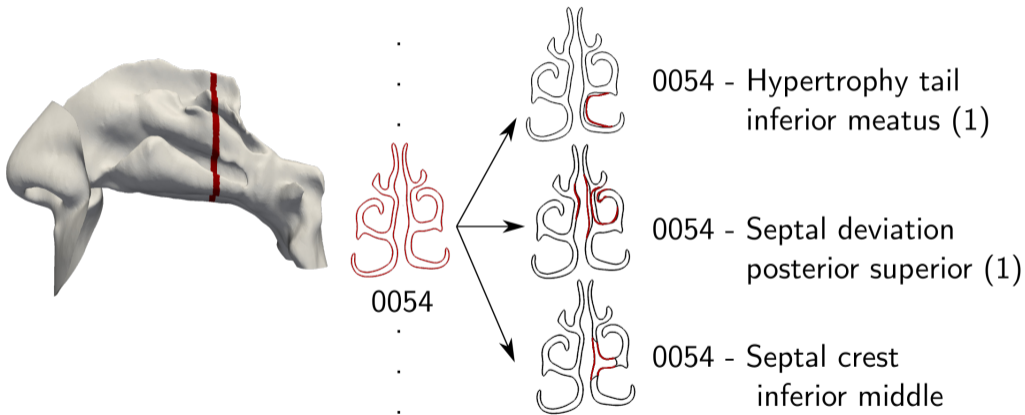
- ▶ In medicine, ML usually means image analysis
- ▶ In rhinology, input to ML **cannot be** the CT scan (cost)
- ▶ Our take: input to ML is the patient-specific flow **computed** from the CT scan
- ▶ The meaningless anatomical differences are filtered out

We are developing a ML-based system to classify pathologies and suggest surgeries

Step 1. Tree of elementary defects/surgeries



Step 2. Inject **virtual anti-surgeries** on **healthy** patients



Step 3. Compute CFD solutions on the synthetic anatomies

- ▶ 277 distinct anatomies are generated from 7 healthy patients
- ▶ Defects are isolated or in combination, various severities
- ▶ Some "features" are extracted from each CFD solution

Step 4. Train a neural network

- ▶ A standard **neural network** is trained to classify pathologies
- ▶ With *k*-fold CV accuracy approaches 100%
- ▶ Simple extra features (e.g. 2 nasal resistances) improve accuracy further
- ▶ Prelim version > 90% accuracy on real patients

Concluding remarks

- ▶ CFD is going to have a **disruptive role** in rhinology
- ▶ **Creativity** is required: classic CFD simulations are useless
- ▶ Highly multi-disciplinary topic: CFD, turbulence, flow control, numerical methods, HPC, adjoint optimization, Machine Learning (plus radiology, physiology, rhinology, surgery, etc!)
- ▶ The role of **AI** is... different

Acknowledgment to the OpenNOSE group!

EXPERIMENTS



SURGEONS



**MACHINE
LEARNING**



CFD

A few references

- ▶ M.Atzori, G.Dini Ciacci and M.Quadrio, *Understanding the mismatch between in-vivo and in-silico rhinomanometry* Med Biol Eng Comput 2025, ArXiv <https://doi.org/10.48550/arxiv.2506.10865>
- ▶ The AMPHIBIOUS open-source DNS solver: <https://www.amphibious.cfd>

Step 3. Transfer defects automatically with functional maps

- ▶ On a **first** healthy patient, realistic deformations are created **by hand** (it takes weeks!)
- ▶ Deformations are applied to other healthy patients via **functional maps**^a

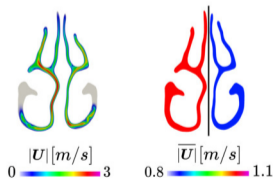
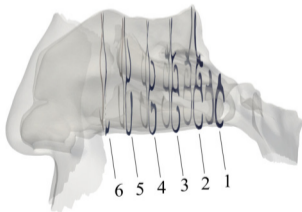


	Healthy		Endoscopic Septal Deviation, medial posterior	
Pat. 0054		Virtual Surgery (Handcrafted)		weeks
Pat. 0058		Virtual Surgery (Functional Map)		minutes
Pat. 0062		Virtual Surgery (Functional Map)		minutes
	⋮		⋮	

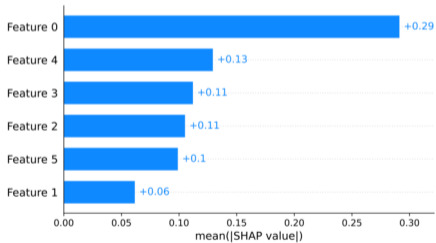
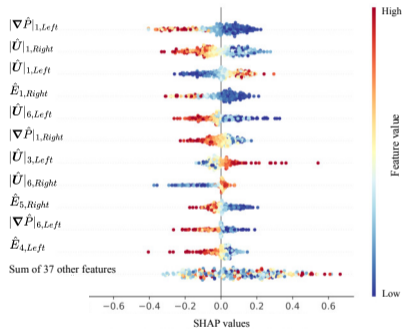
^aOvsjanikov *et al.*, ACM Trans. Graphics 2012

Dealing with the large size of CFD data

- ▶ The number of inputs to the NN must be small (as such is the number of observations)
- ▶ **Manual** feature extraction
- ▶ Two strategies: **regional averages** (of velocity, vorticity, TKE, strain, pressure, pressure gradient, etc), and line integral over **streamlines**



SHAP analysis



Towards physics-based clustering

- ▶ Regional averages: expert-driven, handcrafted features
- ▶ Physics-based clustering: meaningful regions within CFD flow fields identified by **terms of the governing equations**
- ▶ Features are extracted from clusters (set-learning models are employed to process the unordered, variable-sized feature sets)

