TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

The medical digital twin

Unleashing high-fidelity in silico simulations for patient-specific solutions

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In silico?


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UNIVERSITY OF ROME
Moving the boundaries of
in-silico cardiovascular analysis

Agenda

- An overview on Digital Twin
- Medical Digital Twin in EC funded Research
  - MeDiTATe
  - Copernicus
  - DiTAiD

Digital Twin **yesterday**-today-tomorrow

- Digital Twins are nothing new. Today we talk about DT a lot. But we have experience of DT daily use. ABS / ESP in our car. The Prius Hybrid (year 2004)!
- The governing equations of the physics of the twin were previously written by hand and then embedded in the electronics. Software components made up of great skills (for example vehicle dynamics). Telemetry and racing strategies in Formula 1. Advanced control systems on board the products.
- **Matlab Simulink**

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Digital Twin yesterday-**today**-tomorrow

- System integration according to standards (an example are the FMU defined according to the FMI protocol *functional mockup interface*)
- Generic purpose IIoT platforms are available
- Twinning of industrial assets intended for the optimization of service, performance and maintenance
- GE Predix

"Digital twin eliminates the guesswork when determining the best way to service critical physical assets—from engines to power turbines. Easy access to this unique combination of deep knowledge and intelligence about your assets paves the road to optimization and business transformation."

Colin Parris, Vice President
GE Software Research

Digital Twin yesterday-today-tomorrow

- Integration of high fidelity CAE (FEA, CFD, FSI) and system simulation ones (Modelica)
- Combination of AI, Machine Learning and numerical simulation (ROM)
- Hybrid twins combining historic Big Data (when available) with synthetic Big Data by simulation – data fusion
- ANSYS Twin Builder

Ansys

Digital Twin

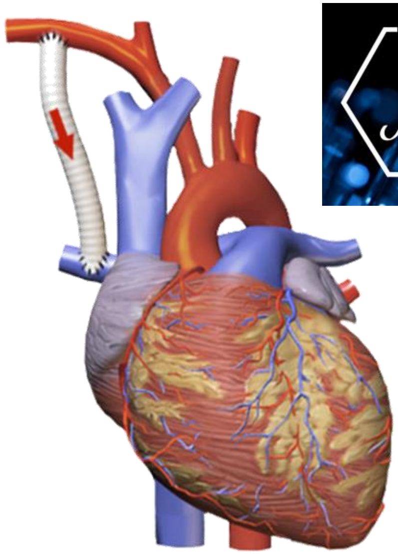
- A digital twin is a digital copy of an existing and working **physical asset**.
- It's connected with the actual state of the asset, remembers its history
- It allows to evaluate more about the current status of the asset. Can be used to forecast its evolution

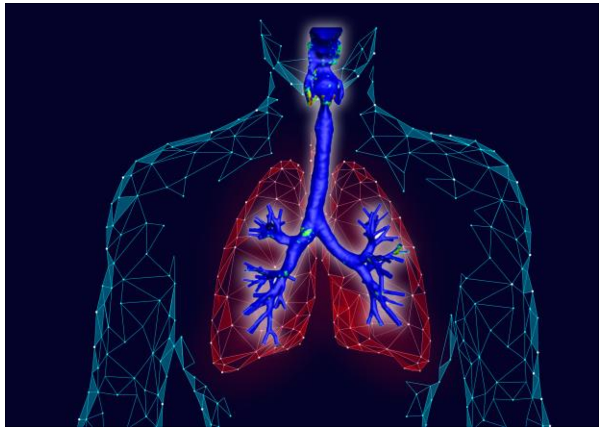
Medical Digital Twin

- Human body is a very important **physical asset**!
- Medical engineering combines **in silico** approach with the in vivo and in vitro ones
- CFD simulation of cardiovascular systems, structural simulations of stress acting on prostheses and on tissues, aerodynamic simulation of airways.
- Patient digital twin (Medical Digital Twin) aims at an easy adoption of in silico results in the medical environment (translation).
- Numerical simulation requires high performance computing (HPC) to have real time usage compression methods (ROM, PCA) are key enablers to adopt digital twin in real time
- Medical digital twin requires the fusion of image data and digital images (interactive visualization), the definition of biomarkers and the presentation of the results with tools and language that can be easily understood by the medical staff.
- https://www.vph-institute.org/history.html

Examples of Medical Digital Twin

- Aneurysms prevention and treatment (MeDiTATe project -The Medical Digital twin for aneurysm prevention and treatment)
- Shunting according to the mBTS (FF4EuroHPC project experiment - Cloud-Based HPC Platform to Support Systemic-Pulmonary Shunting Procedures)
- Patient specific airways treatment (FF4EuroHPC project experiment - Digital-Twin for Airflow and Drug Delivery in Human Airways)

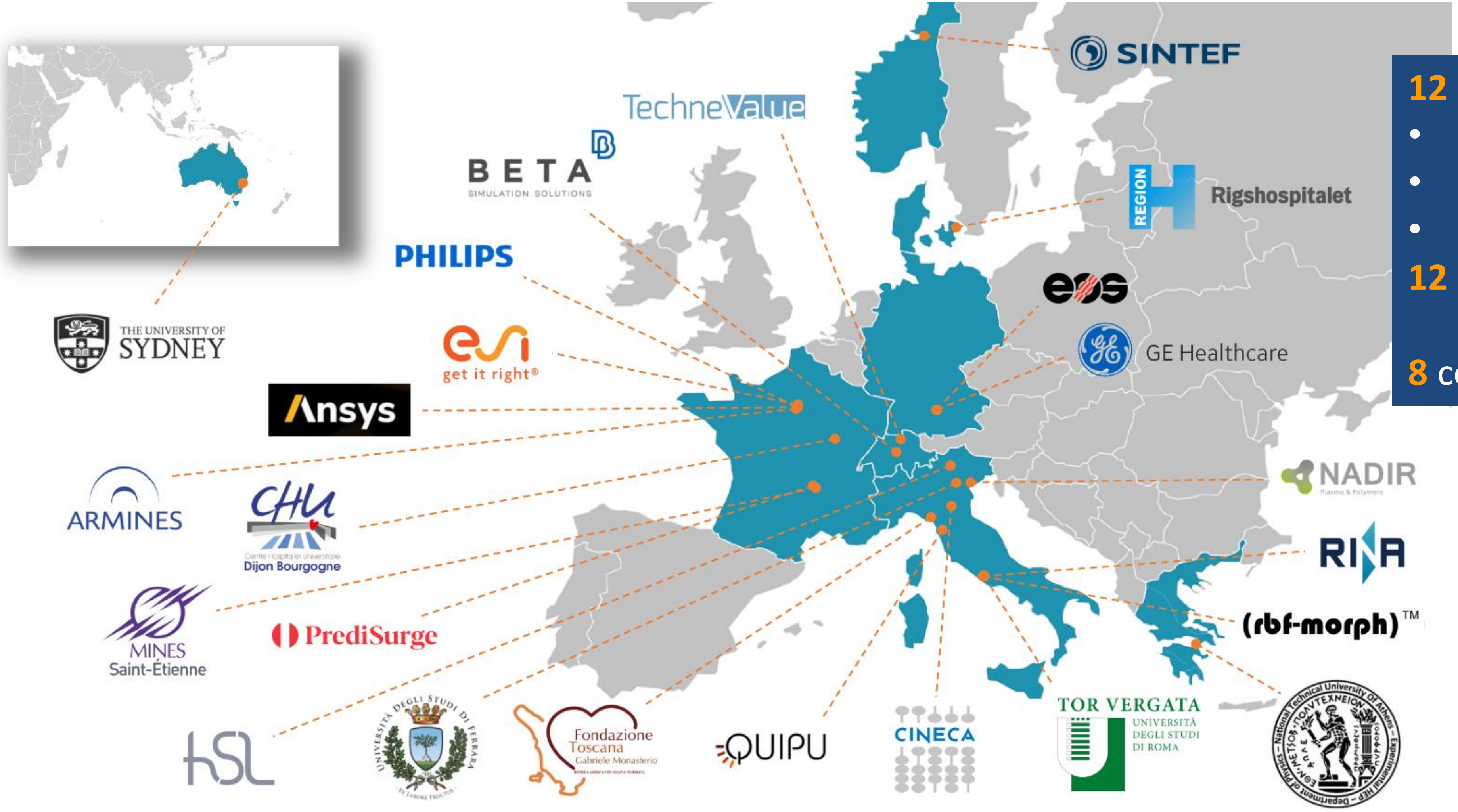




THE MEDICAL DIGITAL TWIN FOR ANEURYSM PREVENTION AND TREATMENT

MeDiTaTe Project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 859836

Consortium



12 beneficiaries
- 3 academic
- 7 industrial
- 2 clinical centres

12 partners

8 countries

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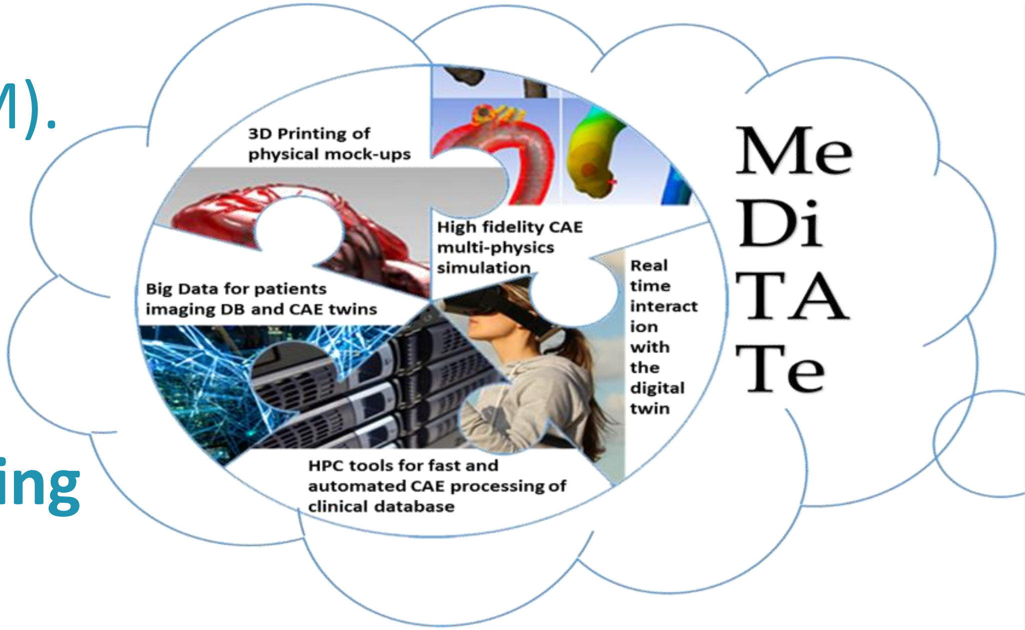
Research Tracks

1. High fidelity **CAE multi-physics** simulation with RBF mesh morphing (FEM, CFD, FSI, inverse FEM).
2. Real time interaction with the Digital Twin by **Augmented Reality**, Haptic Devices and **ROM**.
3. HPC tools, including GPUs, and cloud-based paradigms for **fast and automated CAE processing** of clinical databases.



4. Big Data management for population of patients imaging data and **high fidelity CAE twins**.
5. Additive Manufacturing of **physical mock-up** for surgical planning and training.

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Early Stage Researchers

https://meditate-project.eu/early-stage-reseranchers/














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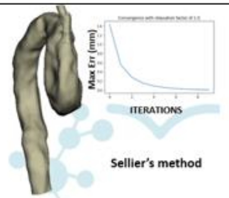
Individual Research Projects

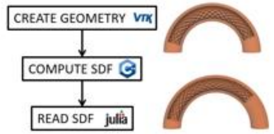
https://meditate-project.eu/phd-projects/

ESR1 Interactive ROM to reshape the aneurysm

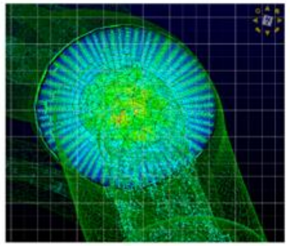


ESR2 Zero pressure shape definition for high fidelity FSI

MEDITATE



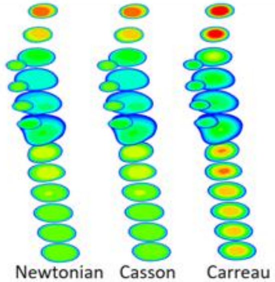
ESR3 Custom FEM beam solver for stent deploy



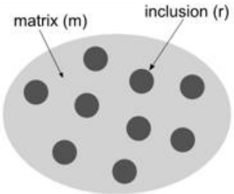
ESR4 Advanced meshing for accurate HiFi GPU simulations

PUMA (NTUA)

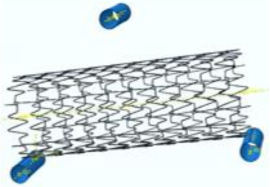
ESR5 FSI coupling simulation accelerated with GPU



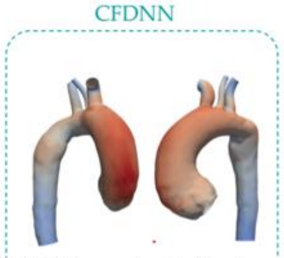
ESR6 Non-Newtonian fluids modelling



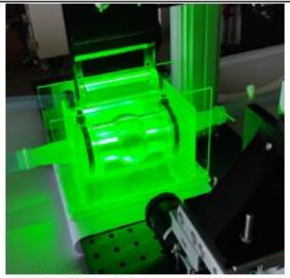
ESR7 Material models matched by FEA identification of image data



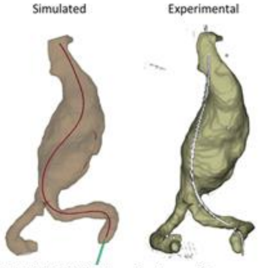
ESR8 Auxetic structures are modelled by nonlinear FEA



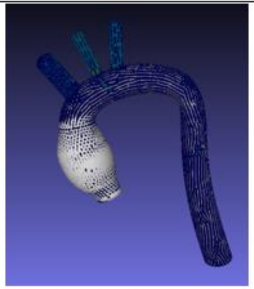
ESR9 CFD computed by Physics informed Machine Learning



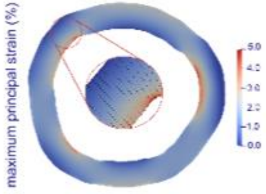
ESR10 PIV validation of CFD simulations of phantoms



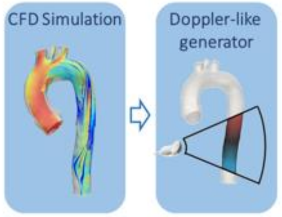
ESR11 FEM simulation of guided navigation



ESR12 RBF Mesh Morphing of patient specific vessels



ESR13 RBF predicted strain map on US images



ESR14 CFD digital twin to simulate US

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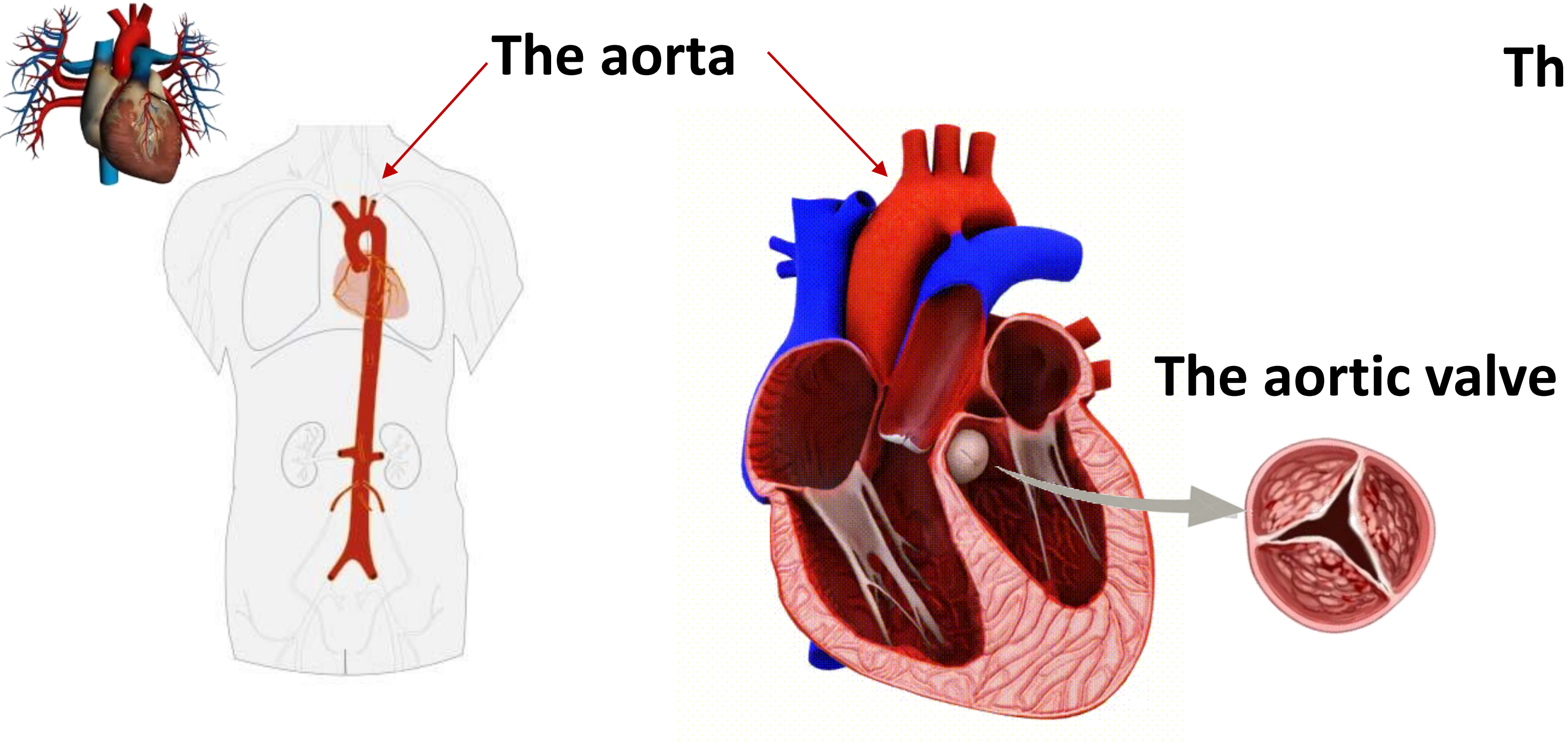
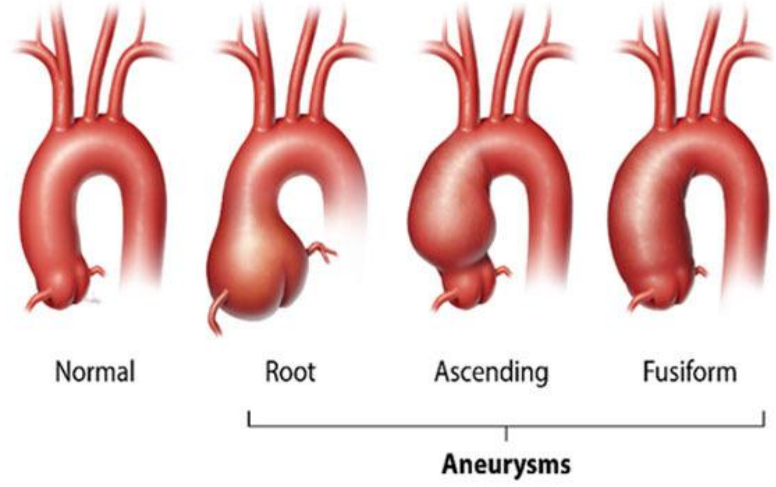
The Anatomy and the Clinical Problem





The **criterion** to perform **ascending aortic aneurysm surgery** is currently based only on the evaluation of the ascending aorta **diameter**.

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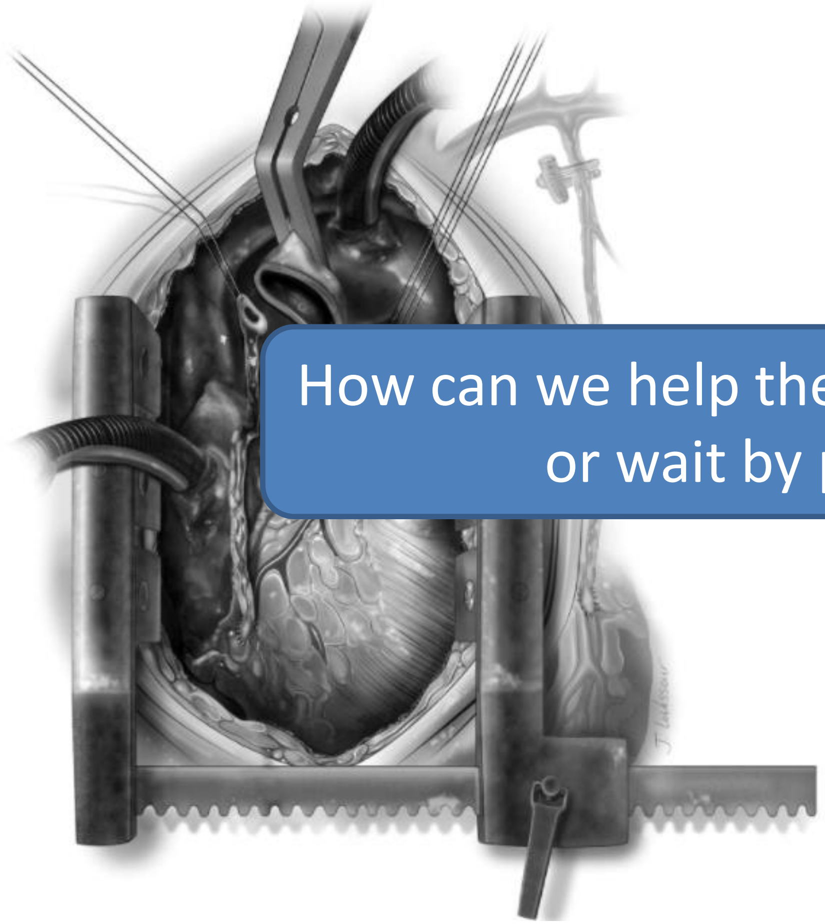
The surgery



How can we help the surgeon in making the decision to perform surgery or wait by providing the patient with a drug therapy?

[1] Leonard N.Girardi, MD, Operative Techniques in Thoracic and Cardiovascular Surgery

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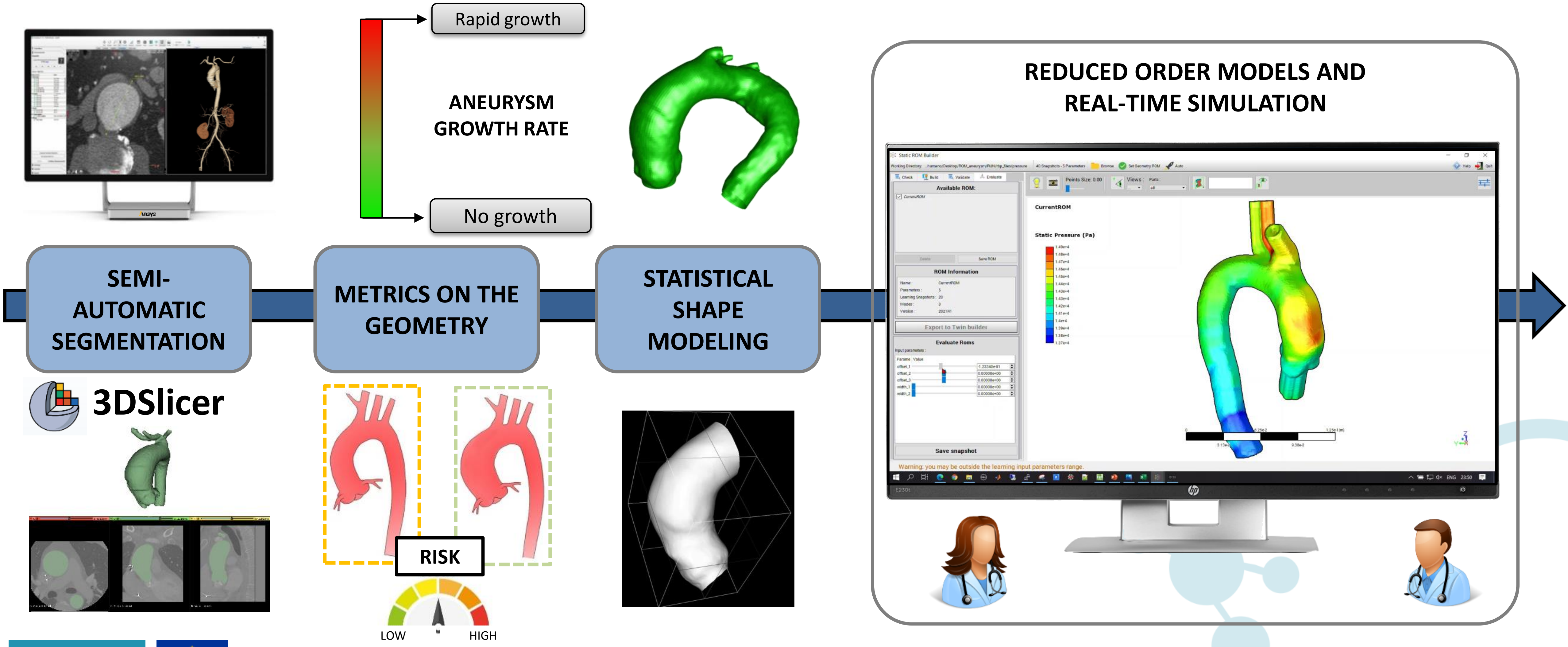
Digital Twin and Real Time Simulation

Creating a workflow to go from images to simulation results in a few seconds...



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FF4EuroHPC

Copernicus

Cloud-based HPC platform to support systemic-pulmonary shunting procedures

InSilicoTrials

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Fondazione Monasterio
la ricerca che cura

RINA

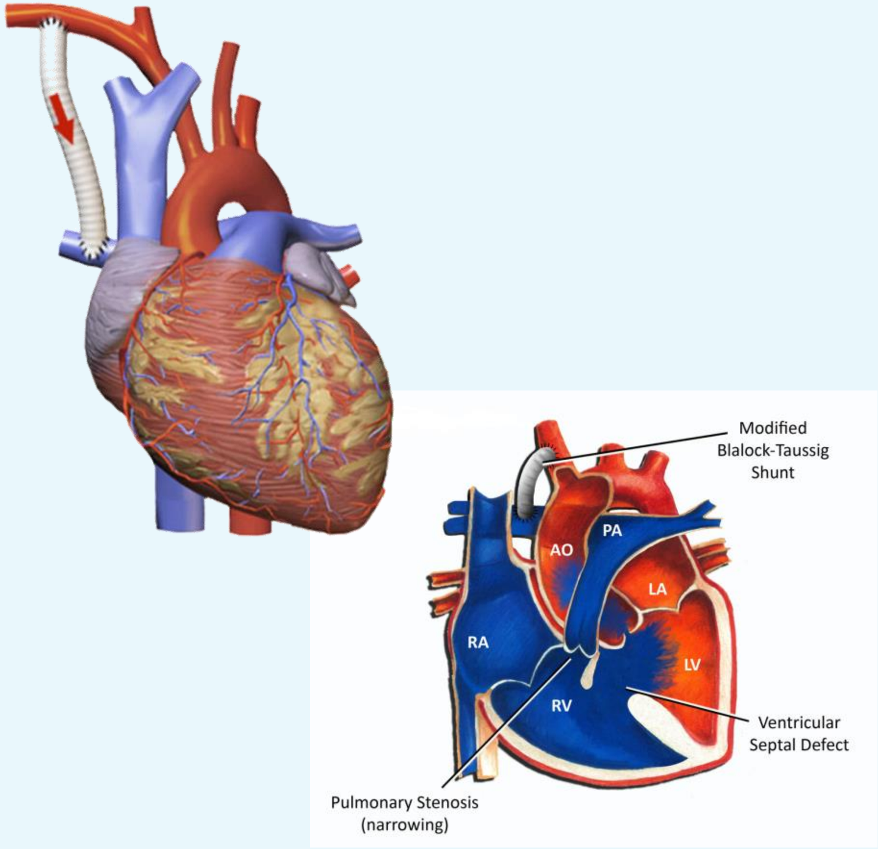
CINECA

This project has received funding from the European High-Performance Computing Joint Undertaking Joint Undertaking (JU) under grant agreement No 951745. The JU receives support from the European Union's Horizon 2020 research and innovation programme and Germany, Italy, Slovenia, France, Spain.

EuroHPC
Joint Undertaking

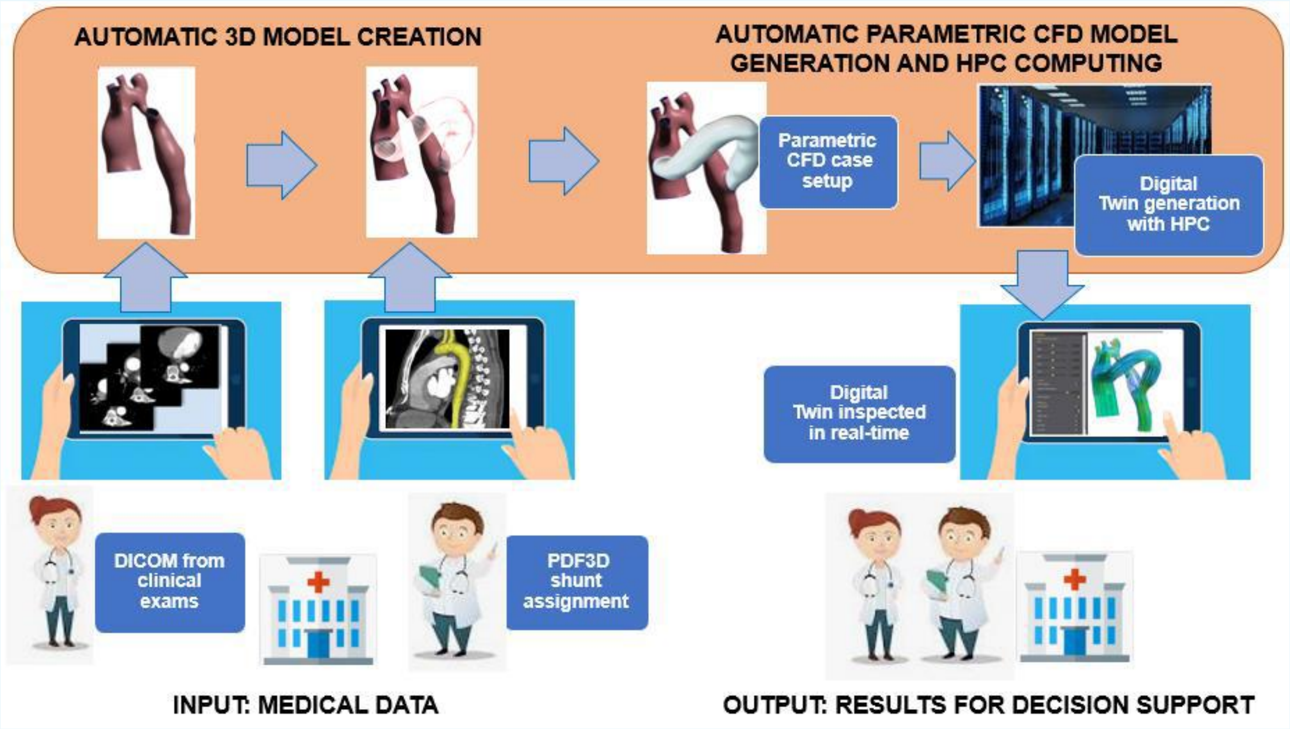
The Problem

- **Congenital heart diseases** (CHDs) account for nearly **one-third** of all congenital birth defects and **7th cause of death** in children younger than 1 year in 2017.
- Without the ability to alter the prevalence of CHD, interventions and resources must be focused to improve **survival** and **quality of life**.
- The **Modified Blalock Taussig Shunt** (mBTS) is a common **palliative operation** on cyanotic heart diseases, but it is associated with **significant mortality** (~7,2%).

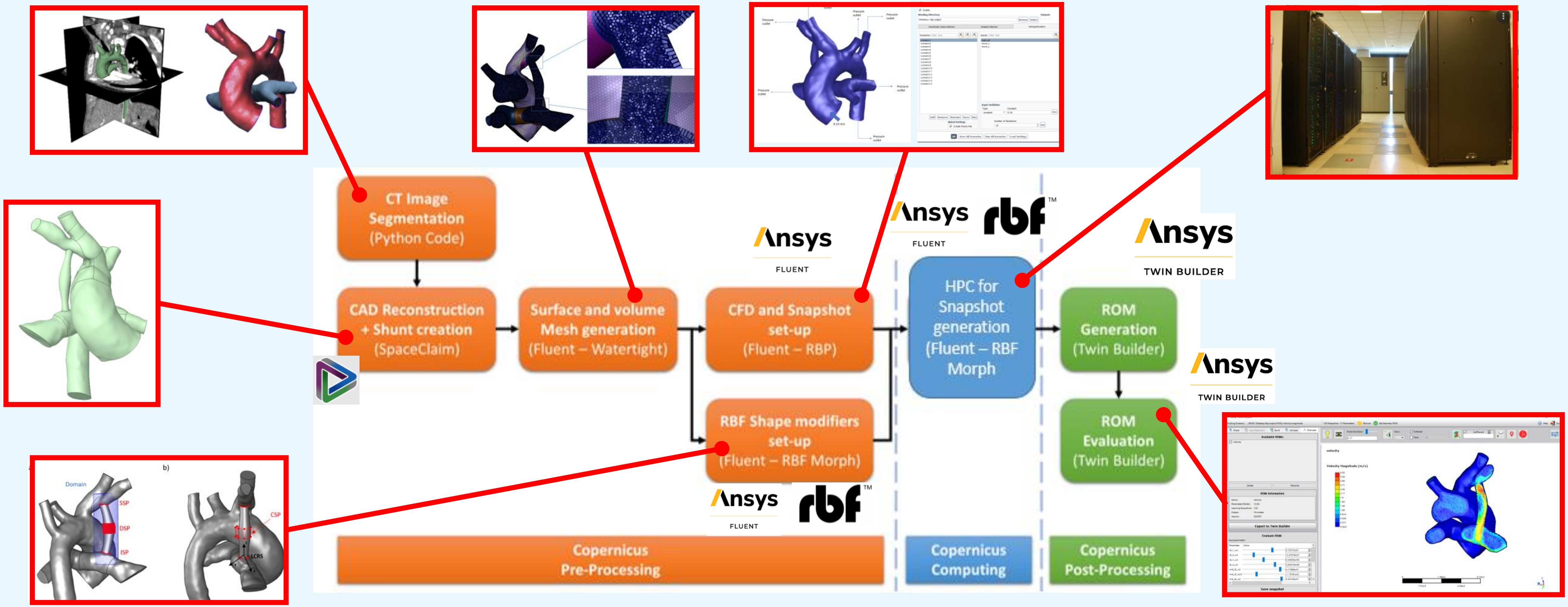


Experiment Approach & Expected Outcome

- The Copernicus application aims to provide an interactive **Medical Digital Twin** (MDT) of the patient-specific district to **support the surgery planning of mBTS under critical conditions**.
- The procedure was designed considering **advanced numerical means** with the objective to deploy MDT within ~**48hh**.



Proposed solution



one simulations
part of Sweco

g/re/p it
High Performance Computing / Linux support / www.grepit.nl

TU Delft
Delft University of Technology

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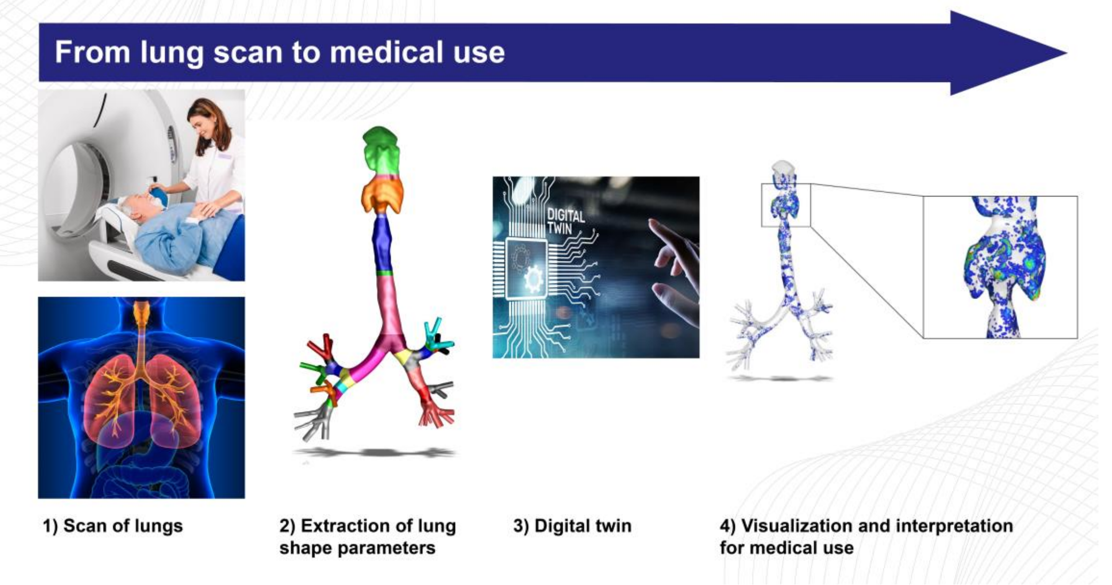
A digital twin for airflow and inhaled drug delivery in human airways

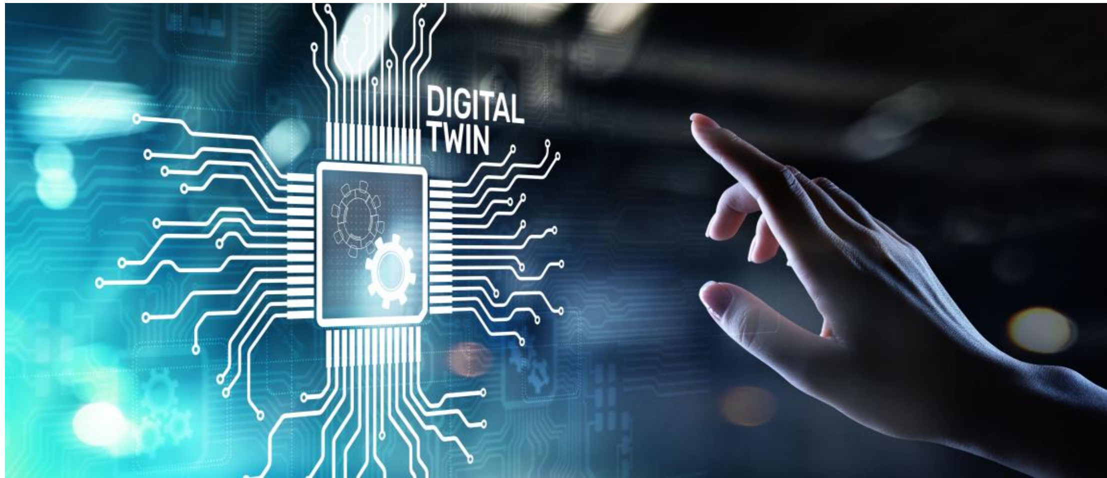
DiTAiD

The digital twin

- **The developed digital twin can:**
  - ✓ **Provide similar results compared to CFD simulations**
  - ✓ **Keeping a good level of detail**
  - ✓ **Provide patient specific results within minutes compared to weeks**

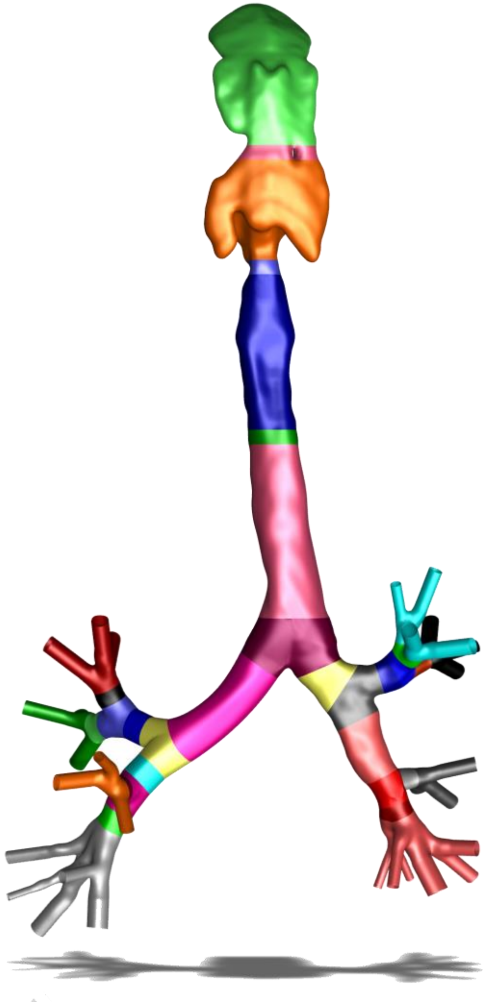


- **The digital twin is created by combining a large number of CFD simulations (snapshots) using Reduced Order Modelling (ROM) techniques**



Lung geometry definition

- **Base geometry is obtained from literature[4]**
  - ✓ **Constructed from several high-resolution CT scans of 47 year old healthy volunteer**
  - ✓ **The base geometry has been studied in multiple experimental and numerical studies[4,5]**
  - ✓ **Includes up to the 4th generation (note, human lungs go up to 23 generations)**



- **Identify relevant input parameters for the digital twin**
  - ❖ **Shape**
  - ❖ **Flow**
  - ❖ **Particle**

[4] Z. Zhang, C. Kleinstreuer and S. Hyun, "Size-change and deposition of conventional and composite cigarette smoke particles during inhalation in a subject-specific airway model," *Journal of Aerosal Science*, vol. 46, pp. 34-52, 2012.
[5] S. Kenjereš and J. L. Tjin, "Numerical simulations of targeted delivery of magnetic drug aerosols in the human upper and central respiratory system: a validation study," *Royal Society Open Science*, vol. 4, no. 12, p. 170873, 2017.

Identify shape parameters

Potentially a huge amount of shape parameters!

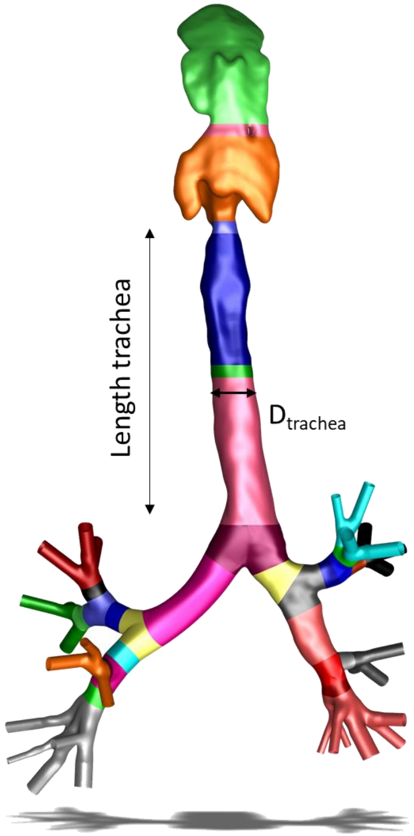
Amount of input parameters is limited by assuming:

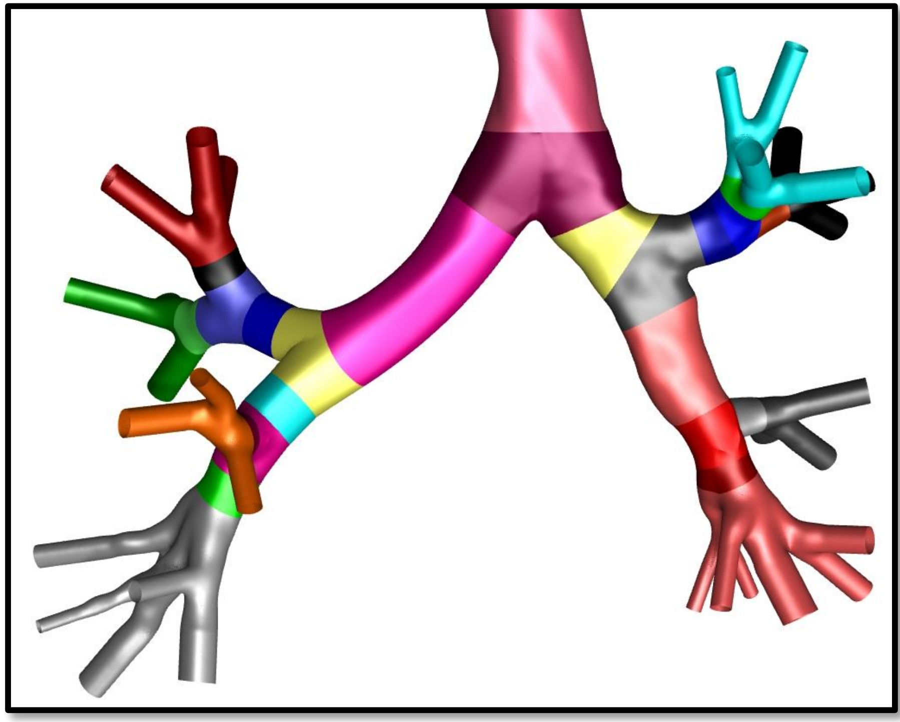
- Circularity is kept constant
- Only considered angle is the branching angle
- Diameter follows a fixed ratio[6] of h=0.79

Mouth-throat part: 3 parameters

Lower airways: 23 parameters

- Generation 0 (trachea): 1L, 1D, 1A
- Generation 1: 2L, 2A
- Generation 2: 4L, 4A
- Generation 3: 8L





Generation	Diameter [mm]	Length [mm] Left	Right	Branching angle [deg]
0 (Trachea)	15 - 20	100 - 120		80 - 95
1		51 - 57	24 - 28	75 - 90
2		12 - 16	15 - 28	65 - 95
3		7 - 10	7 - 10	55 - 70

[6] T. Van de Moortele et al.; *"Morphological and functional properties of the conducting human airways investigated by in vivo computed tomography and in vitro MRI"*

Identify flow & particle parameters

https://www.flickr.com/photos/aceofknaves/25604600281/

Physical parameters: 3 parameter

- Flow rate varies between 15 L/min and 120 L/min
- Particle size varies between 0.1 µm and 10 µm
- Particle injection rate varies between 0 m/s and 10 m/s

26 shape parameters and 3 physical parameter

29 input parameters in total

Parametric study

one simulations
part of Sweco

- **Design Of Experiments (DOE) table is generated:**
  - For the 29 input parameters
  - Using the Latin Hypercube Sampling for optimal spacing
  - Creating 1000 design points
- **Fluent settings validated in literature[5]**
  - Steady state
  - RANS, transitional SST (4eq)
  - Particles are one-way coupled

Ansys Fluent

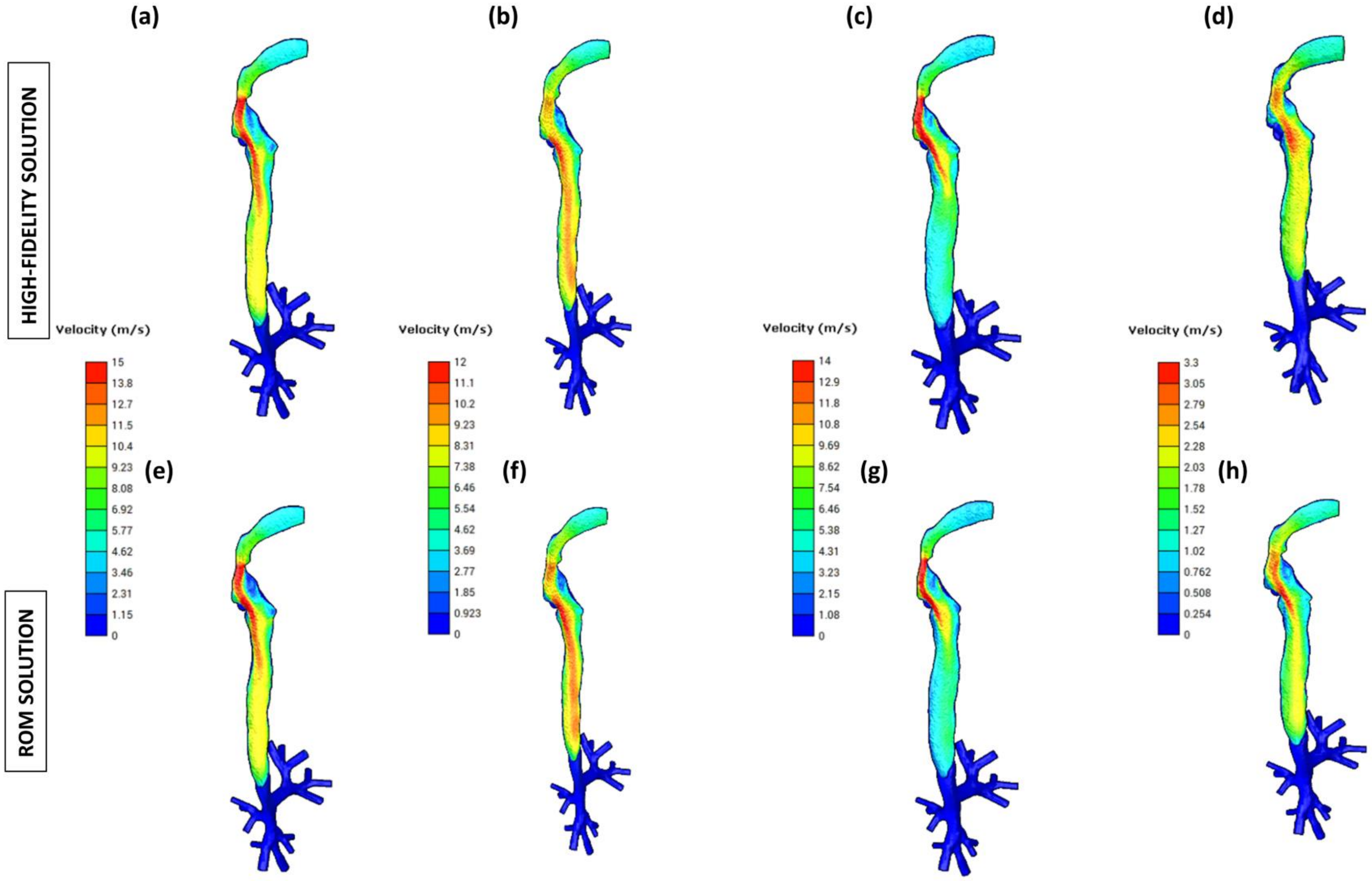
Read base case
Update shape
Update flow/particle parameters
Solve flow
Solve particles
Export snapshot

DOE table

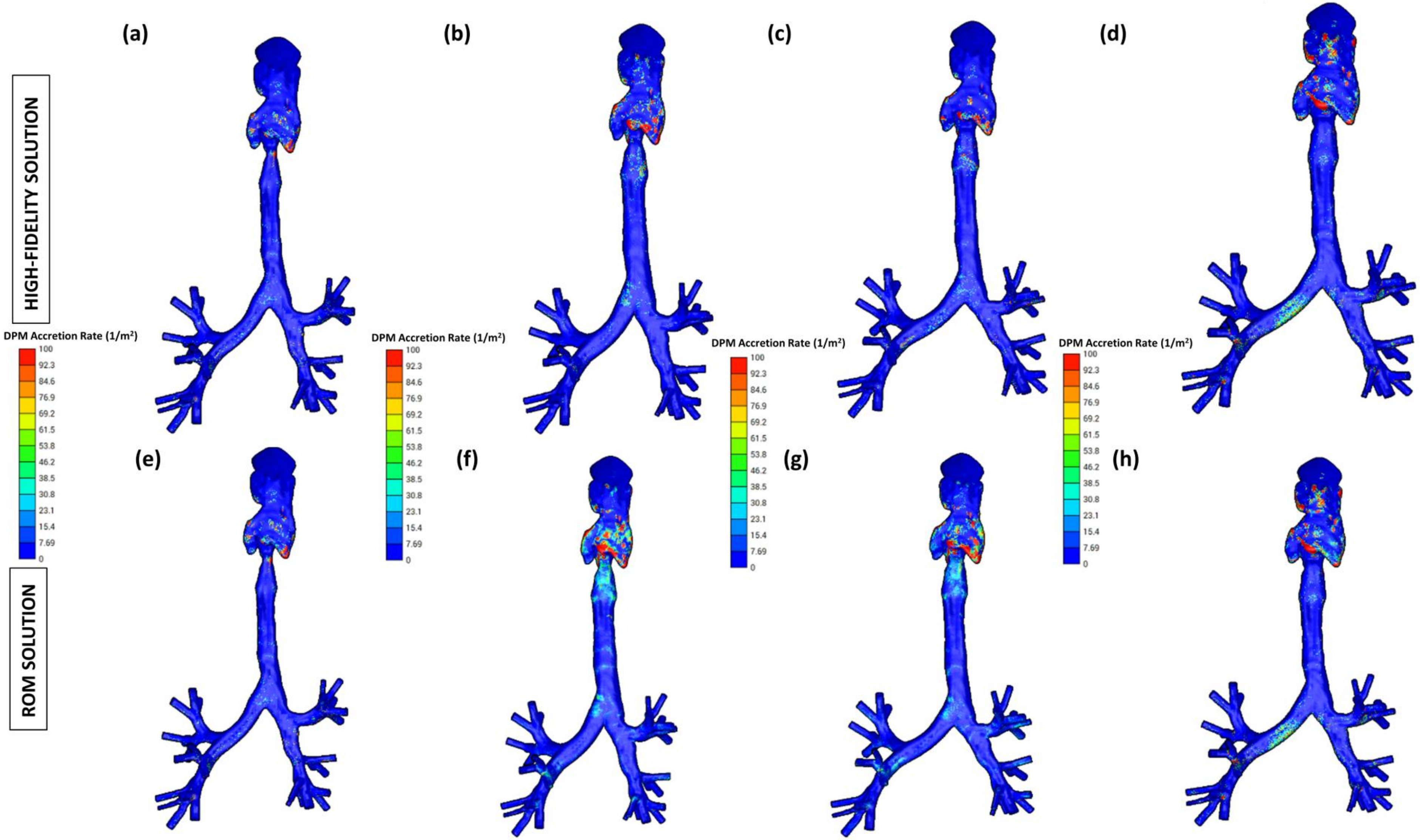
Ansys Twin Builder

[5] S. Kenjereš and J. L. Tjin, "Numerical simulations of targeted delivery of magnetic drug aerosols in the human upper and central respiratory system: a validation study," *Royal Society Open Science*, vol. 4, no. 12, p. 170873, 2017.

Results: Velocity



Results: Particle deposition



Conclusions

- Medical Digital Twins are feasible today!
- The **In Silico** path, i.e. MDT driven by high fidelity simulations, is ready and requires
  - Patient specific data (from images)
  - State of the art multi-physics simulation
  - Reduced order models and advanced mesh morphing
- A clear **business model** is required
  - Public funds are today the major resource
  - Certification is complex
- We are moving in the right direction and there is **mainstream focus** on Medical Digital Twins

TIM
GRUPPO TIM

Meta

Thank you!

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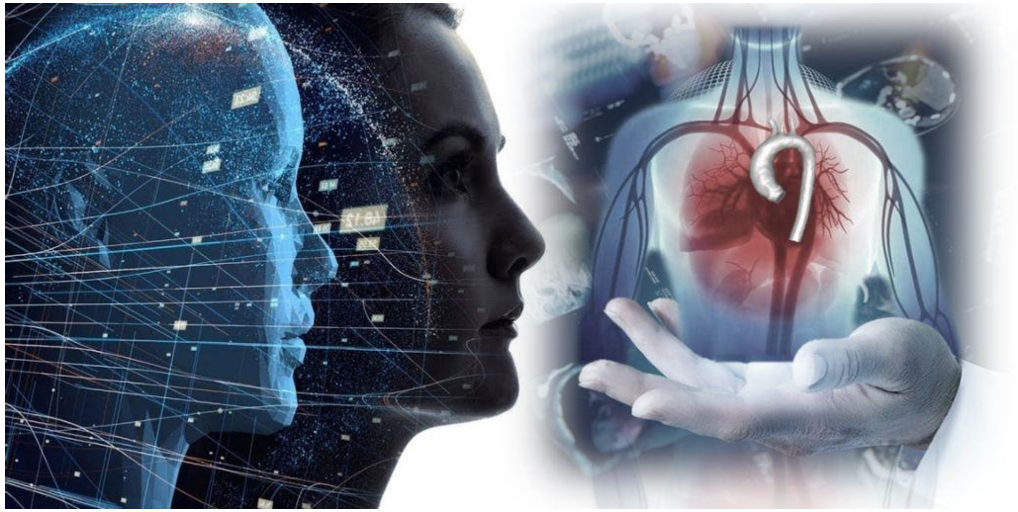
https://www.rbf-morph.com/

https://www.linkedin.com/in/marcobiancolini/

https://www.youtube.com/user/RbfMorph



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