Numerical investigation into the effects of ageing on the geometry and air conditioning capacity of the human nasal cavity

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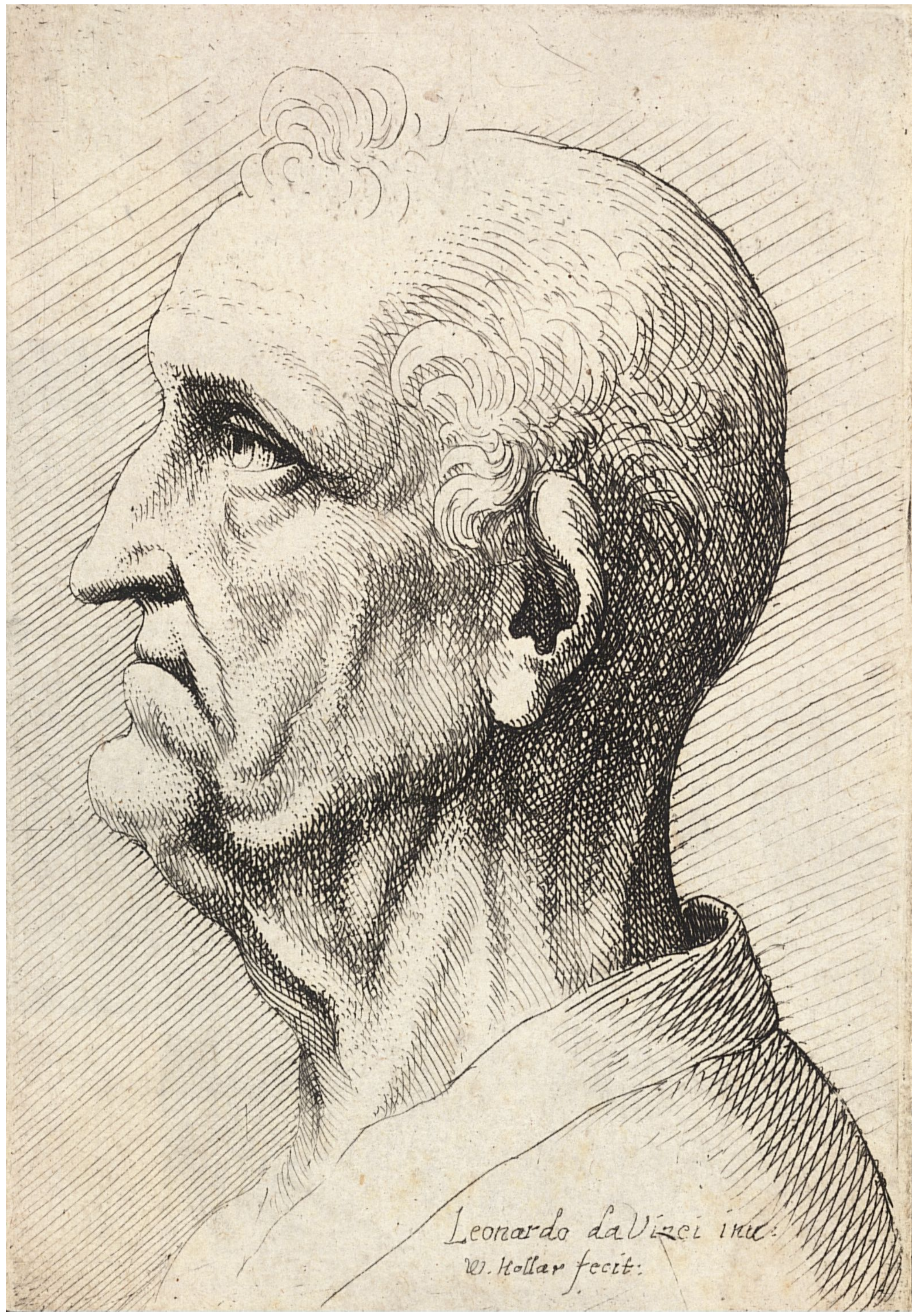
Outline

- Background and literature review
- Research questions
- Research objectives
- Progress to date
- Future work

Background

Older nose have different geometries to those of young healthy adults

These differences can impact on the quality of life of the elderly

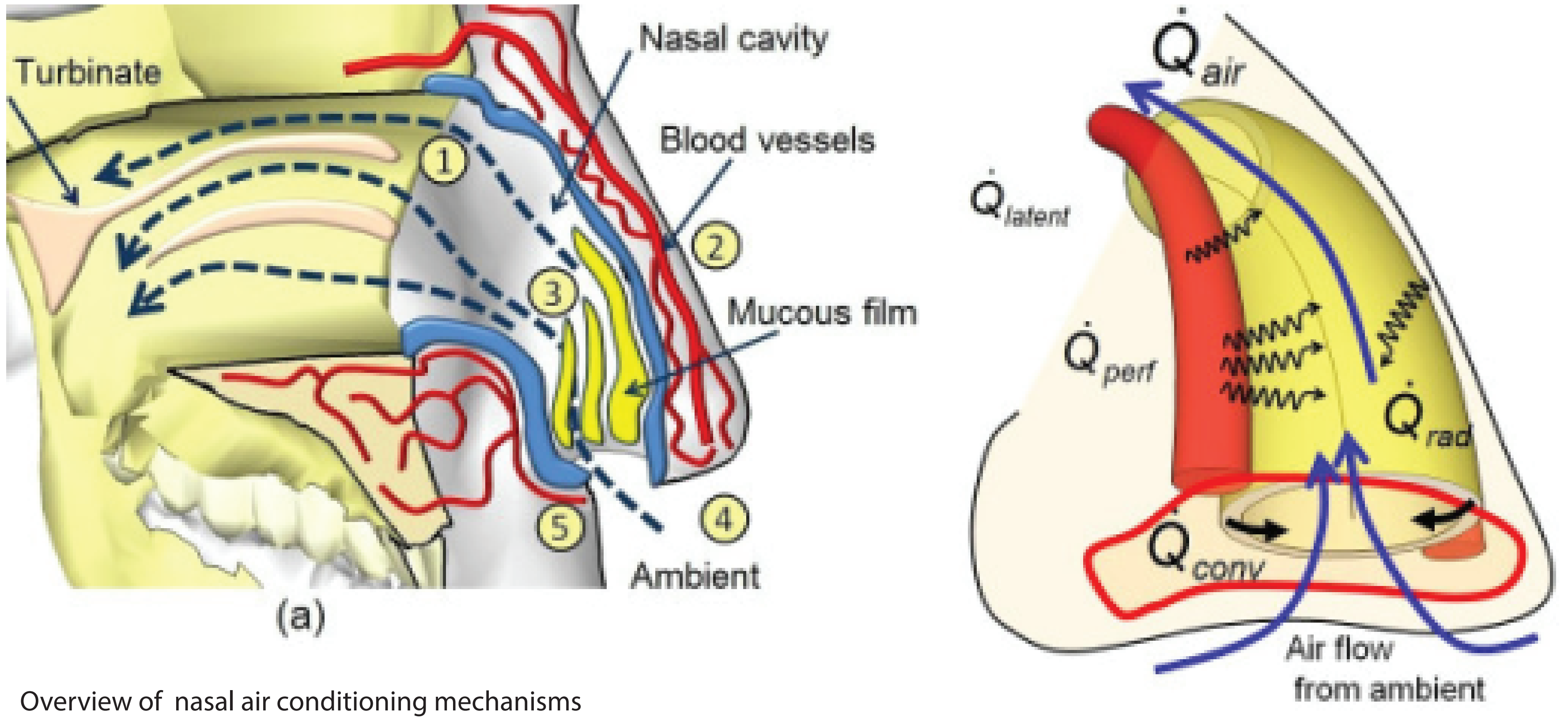


Air conditioning

Significant function of the nose

Conditions the air for interaction with the lungs

Sensitive to geometry



Overview of nasal air conditioning mechanisms

Picture from Abbas, Abbas K et al. “Neonatal Non-Contact Respiratory Monitoring Based on Real-Time Infrared Thermography.” BioMedical Engineering OnLine 10 (2011)

Rhinological disease

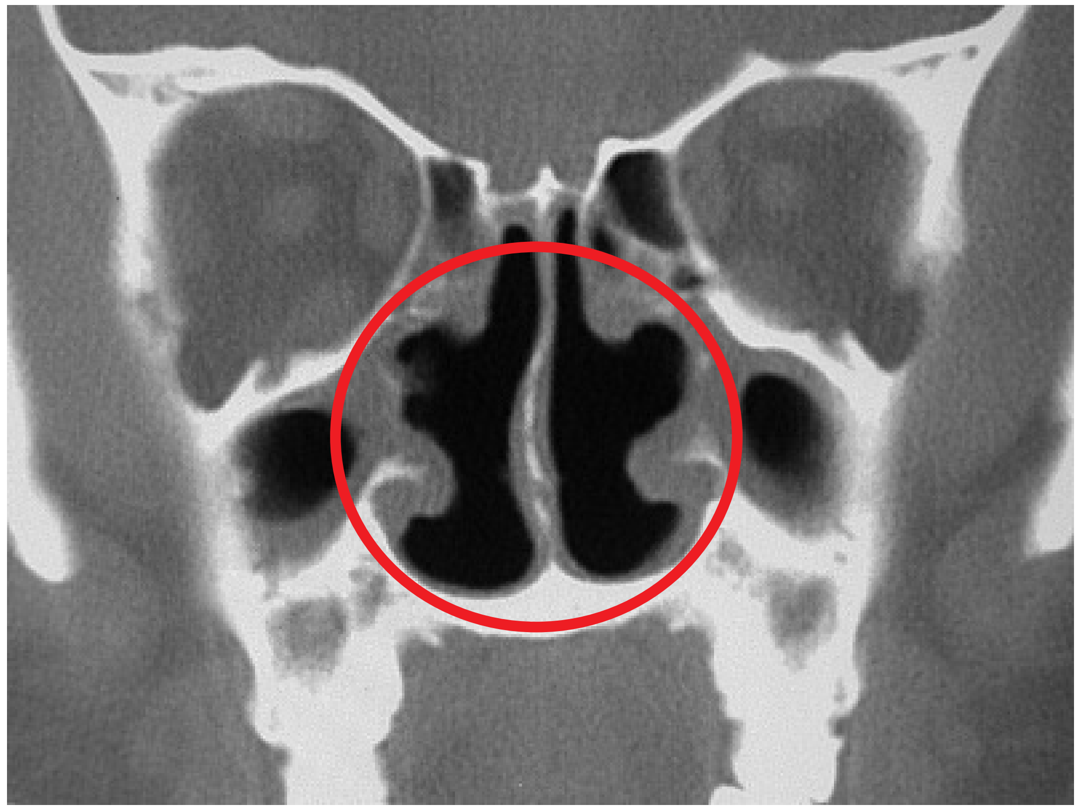
Atrophic rhinitis

More common in the elderly

Linked to geometry

Linked to air conditioning functionality

Atrophic rhinitis



Healthy nasal cavity

Investigations to date

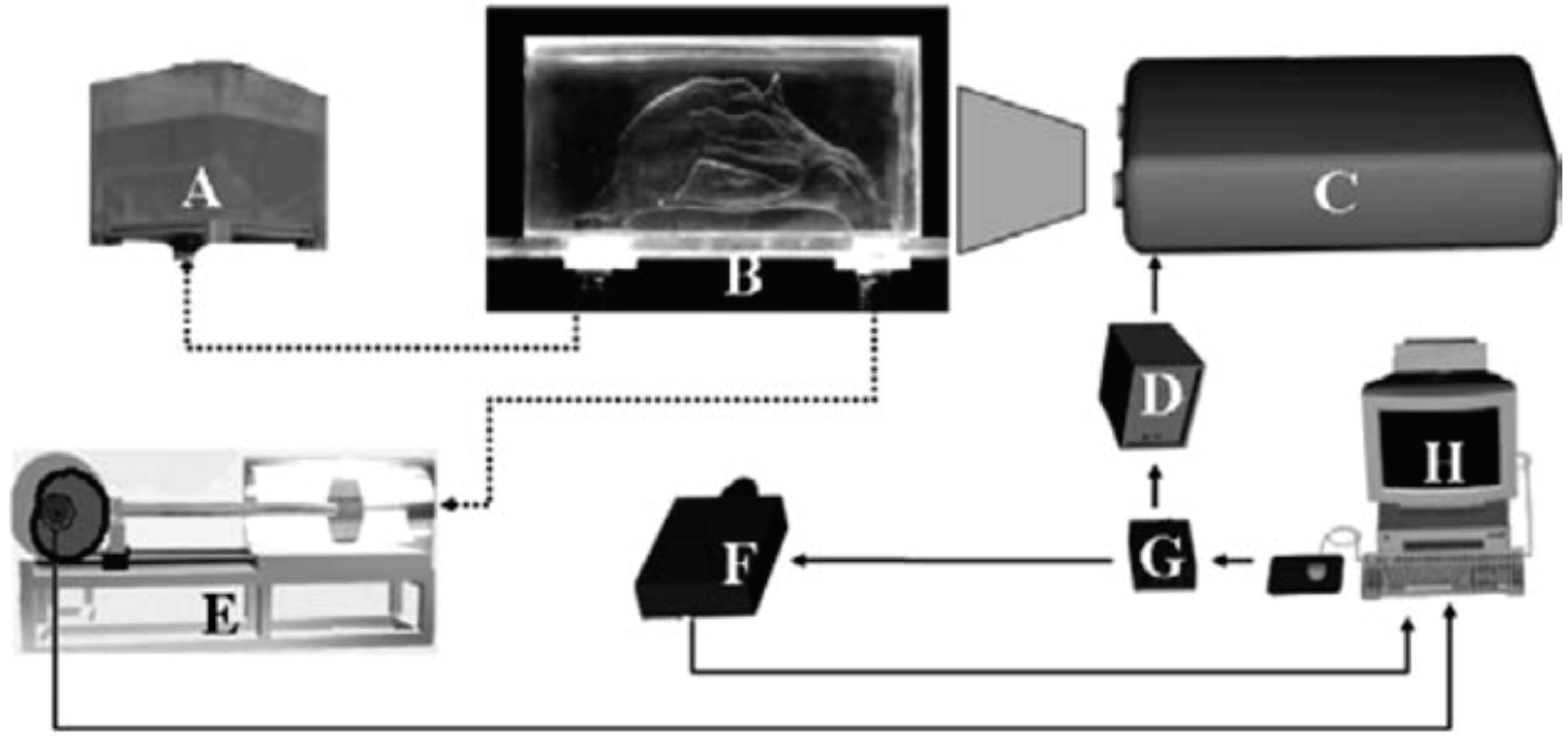
Acoustic rhinometry

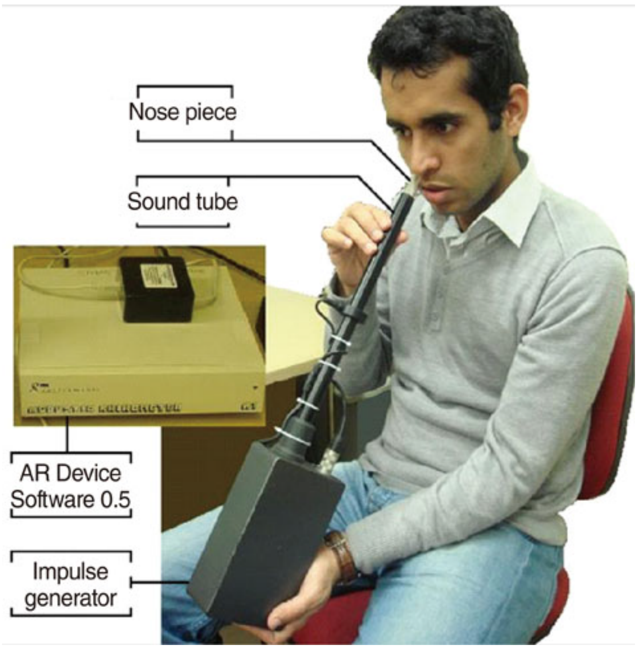
Results show significantly increased volume in elderly specimens

Limited detail about geometry

PIV

No data about heat and vapour transfer





PIV scheme image taken from Chung et al "Nasal Airflow During Respiratory cycle" Am J Rhinol 20 (2006)

Acoustic Rhinometry equipment and outputs(bottom) and PIV set up (top)

Computational fluid dynamics (CFD)

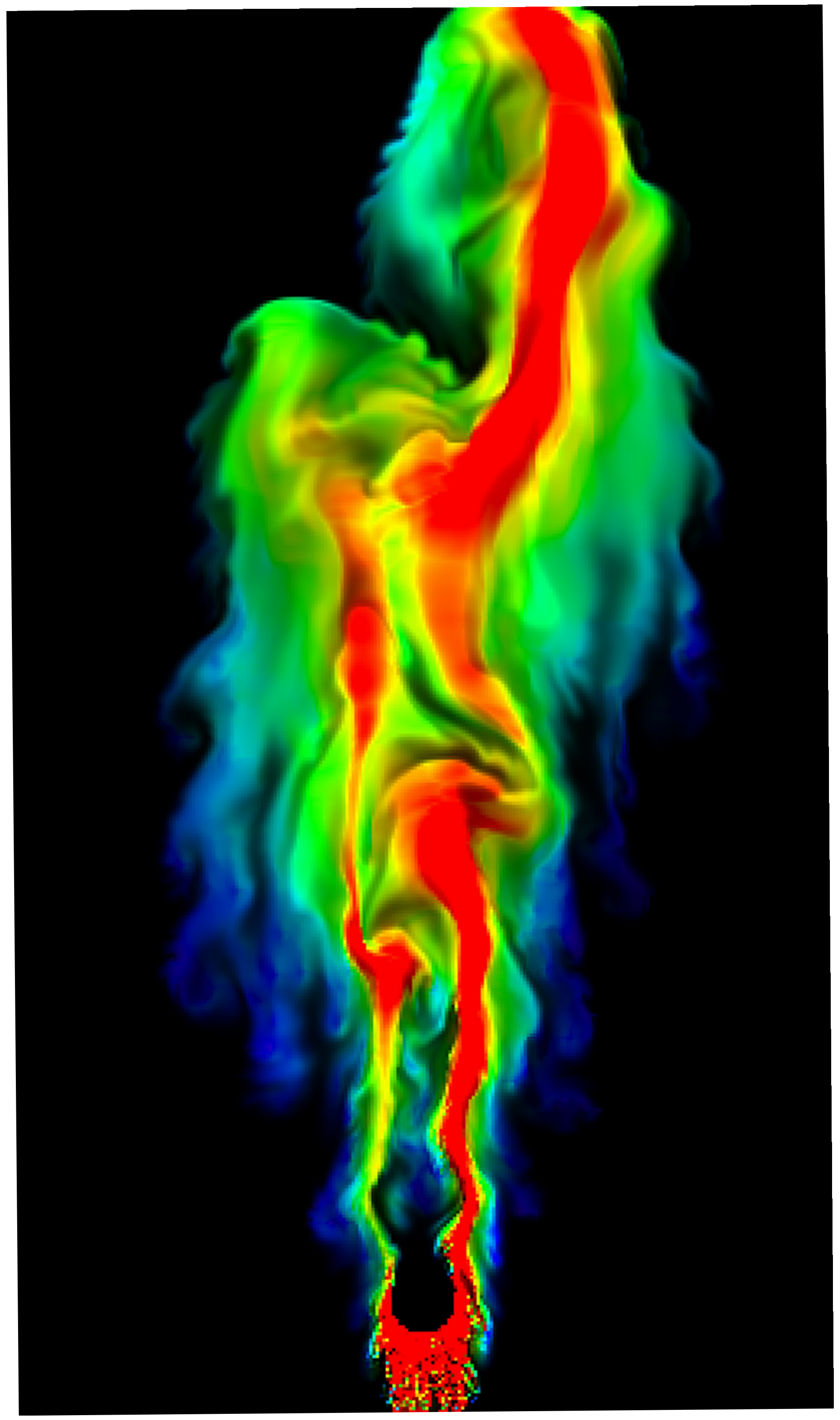
Nasal cavity is primarily a fluent system

Solve discretised Navier Stokes equations for specified boundary conditions

Cost effective

High Detail

More and more powerful with increasing computational capacities



Von Karman vortex street

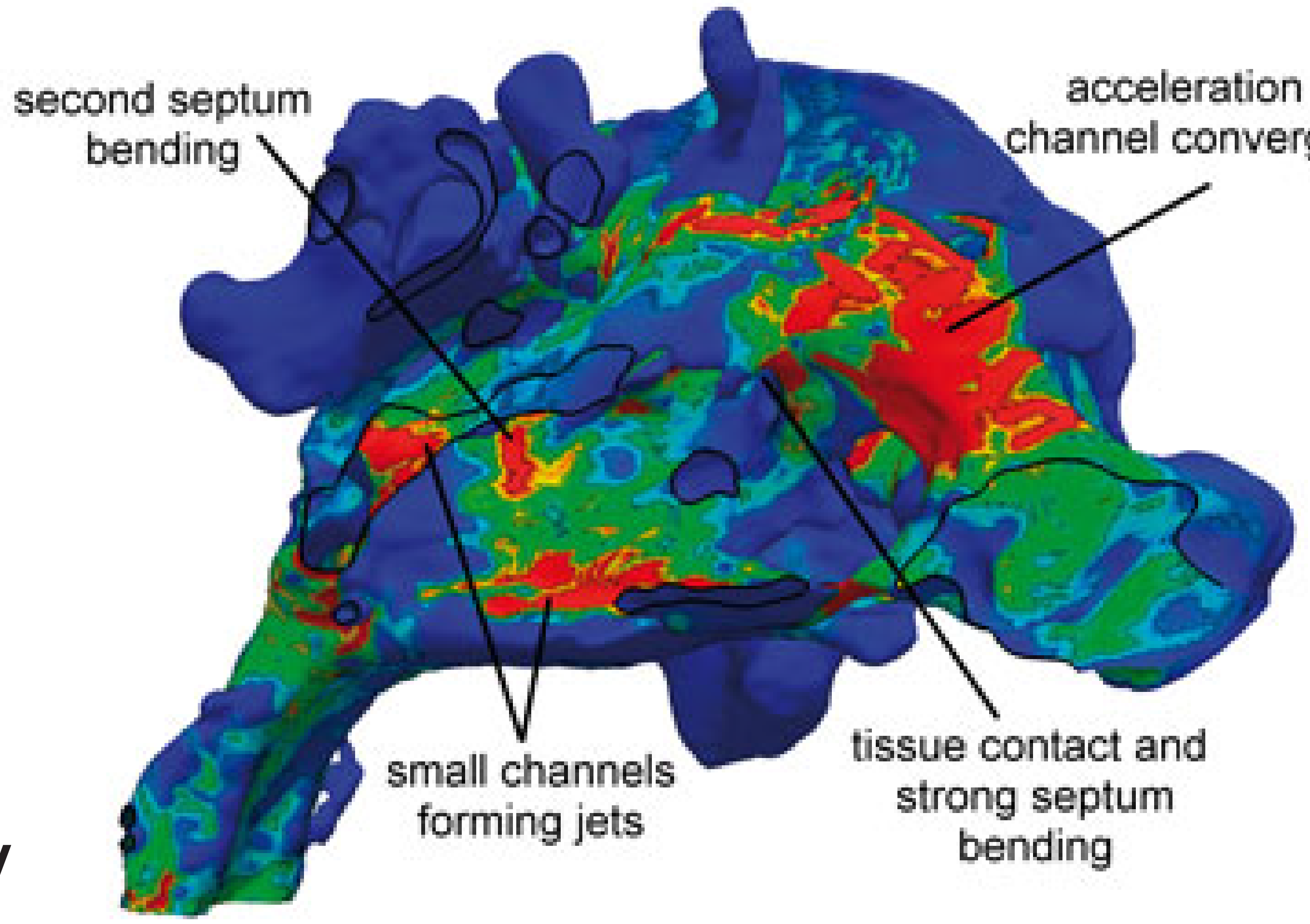
CFD of nasal cavities

Using data from CT scans

Accurate and detailed geometry

Highly detailed flow visualisations

Potential to investigate many aspects of nasal cavity and respiratory system functionality



Picture from Lintermann, A "Simulation of Nasal Cavity Flows for Surgery Environments." Inside 10 (2012)

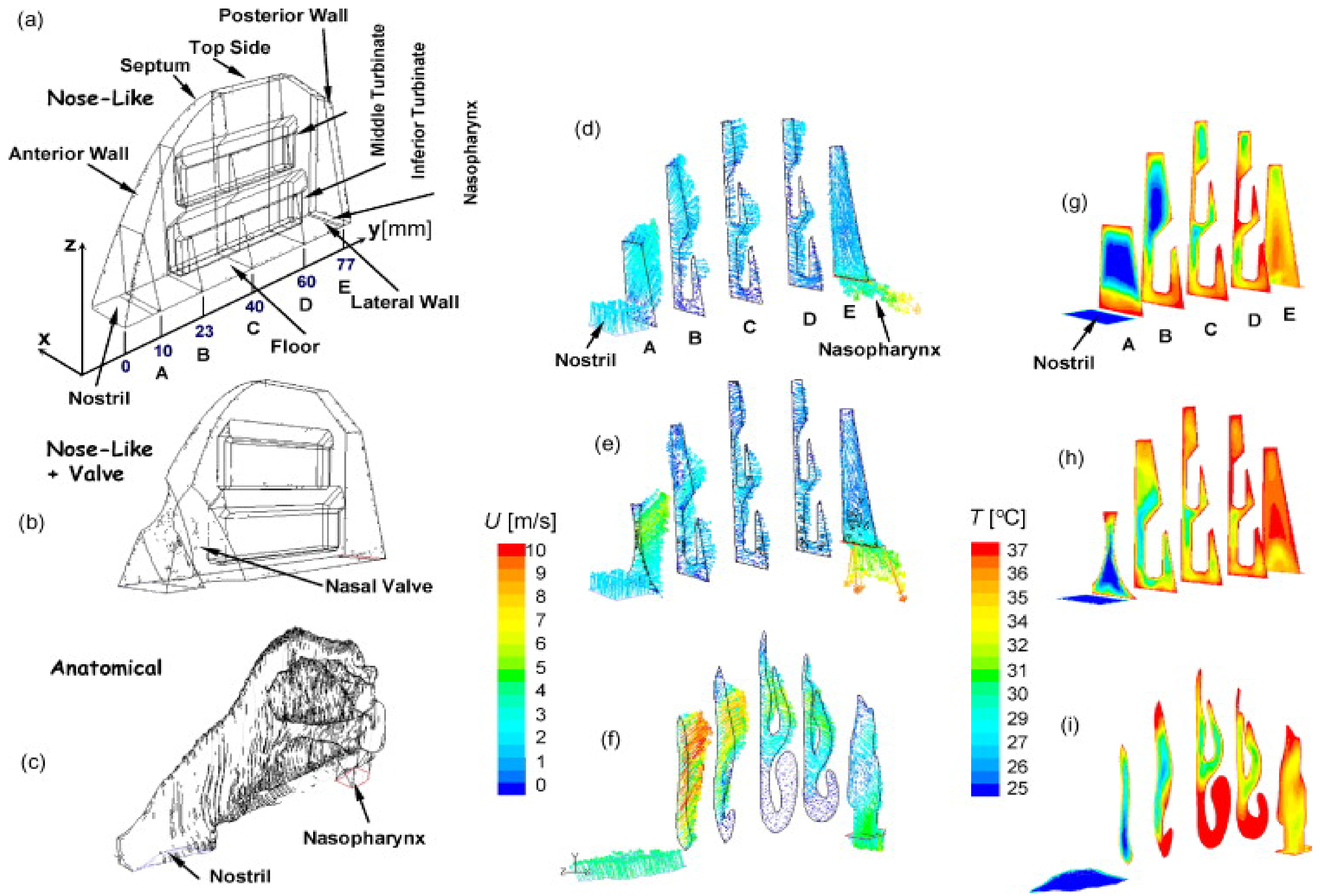
Air conditioning

CFD also allows the modelling of heat and vapour transfer

Humidification and heating mechanisms modeled

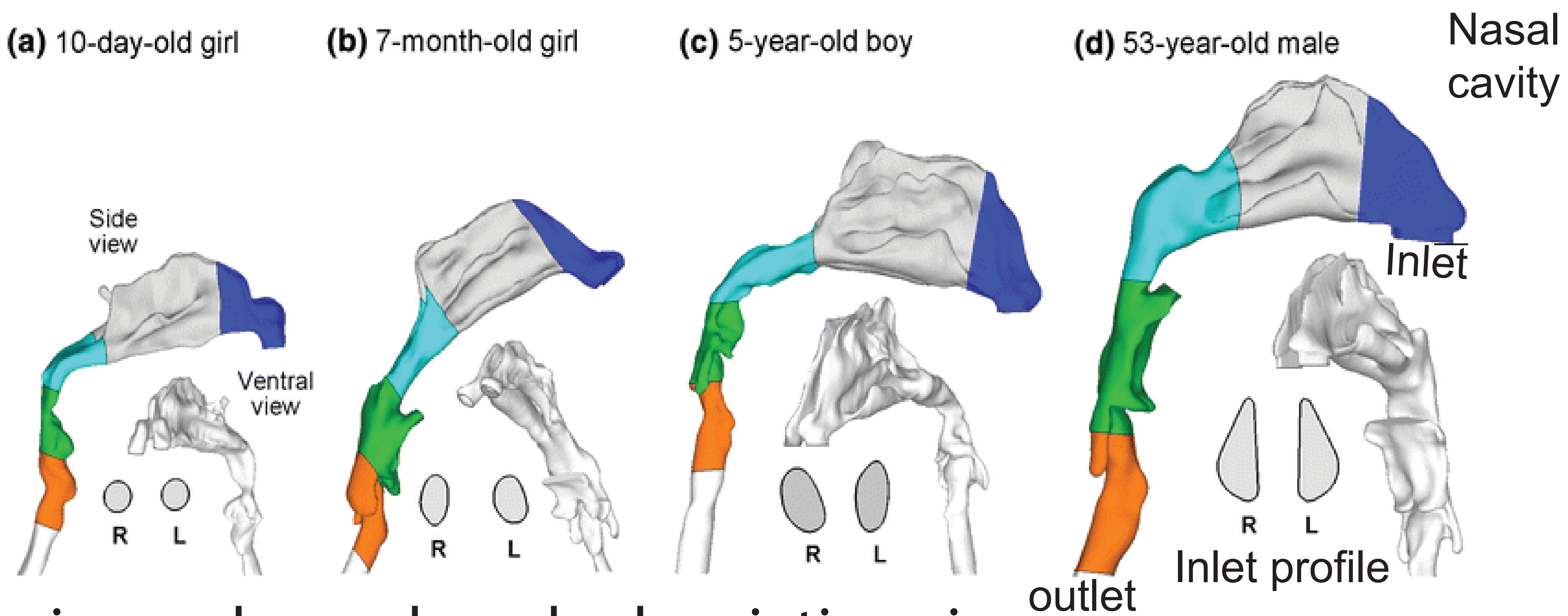
Details of the transport mechanisms can be predicted

Atrophic rhinitis model



Picture from Elad, D. Wolf, M. & Keck, T. "Air-conditioning in the Human Nasal Cavity" Respiratory Physiology & Neurobiology 163 (2008)

Demographic comparison



Age comparisons showed marked variations in flow structures

Ethnic comparisons

Sex comparisons

Requires more study, standardisation

Picture from Xi, J.; Berlinski, A., Zhou, Y., Greenberg, B. & Ou, X. "Breathing Resistance and Ultrafine Particle Deposition in Nasal-Laryngeal Airways of a Newborn, an Infant, a Child, and an Adult" Annals of Biomedical Engineering (2012)

No elderly computational models

Research Questions

- What discrepancy can be noted in the airflow patterns of elderly nasal cavities and those of healthy young adults

- What is the primary cause for the observed discrepancy in the air conditioning capacity of elderly nasal cavities

- What are the aspects of nasal geometry that significantly determine flow characteristics within the nasal cavity

Objectives

- Compare the geometry of the nasal cavity of young and old adult human East Asian male specimens
- Numerically investigate variations in the flow characteristics young and old East Asian male specimens
- Numerically investigate variations in humidification and thermal regulation functionality of the nasal cavities between young and old human adult East Asian male specimens

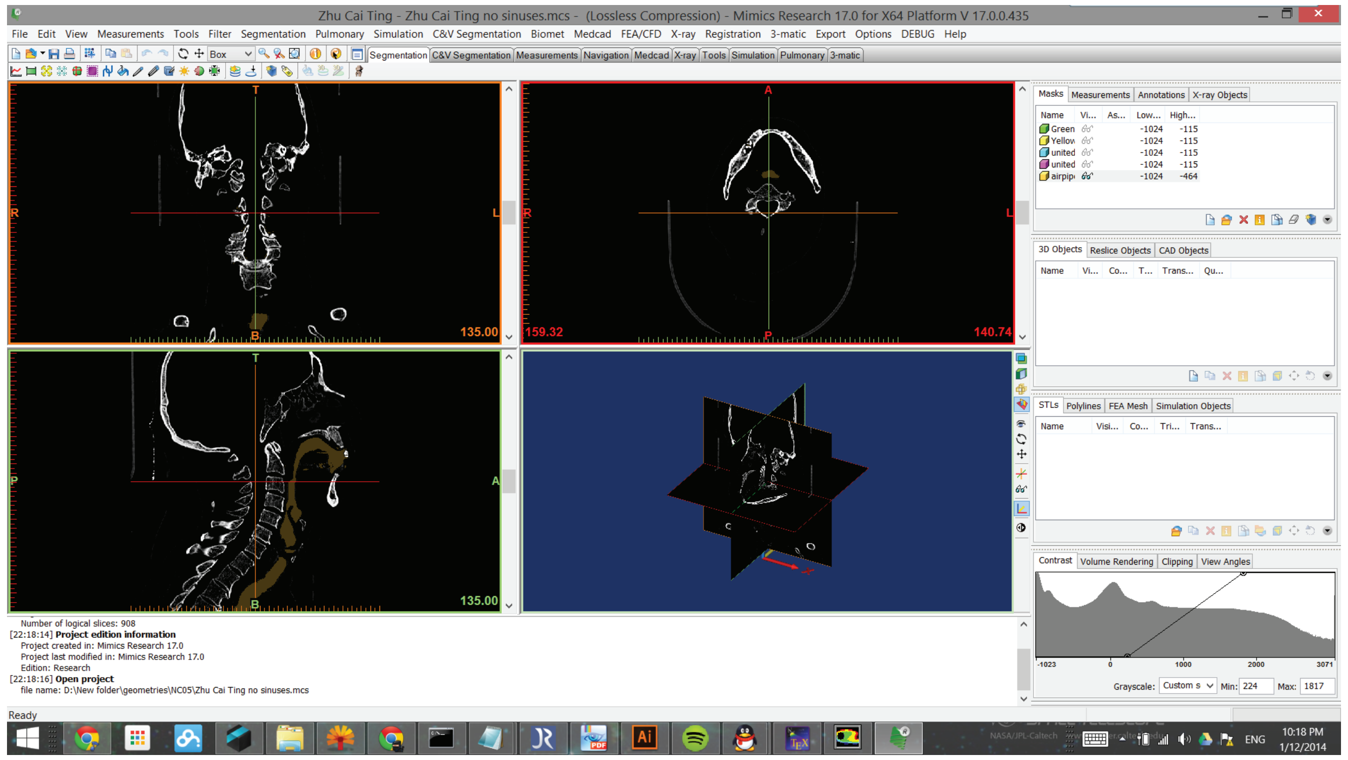
Progress to date

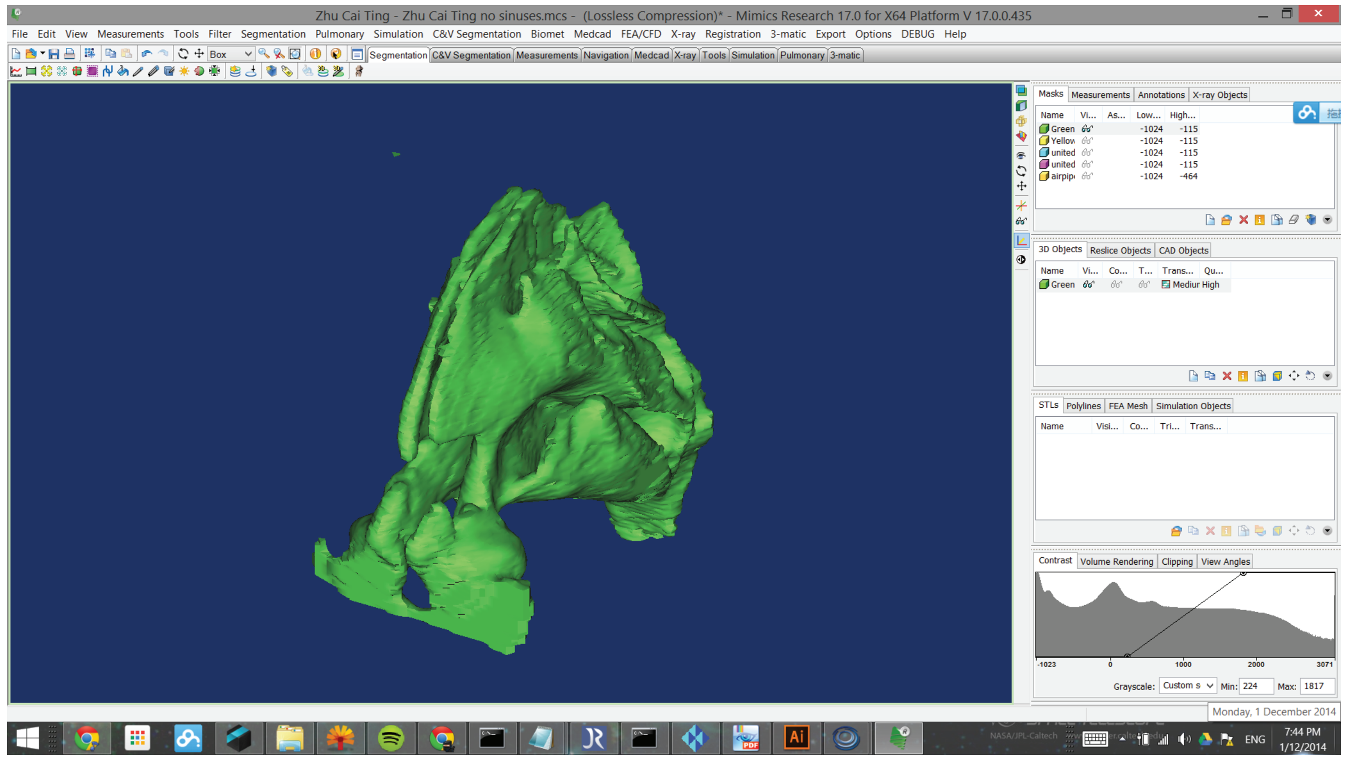
CT scans taken from 78 year old East Asian man

Reconstructed using MIMICS

Thresholding used to extract models

Image manually refined





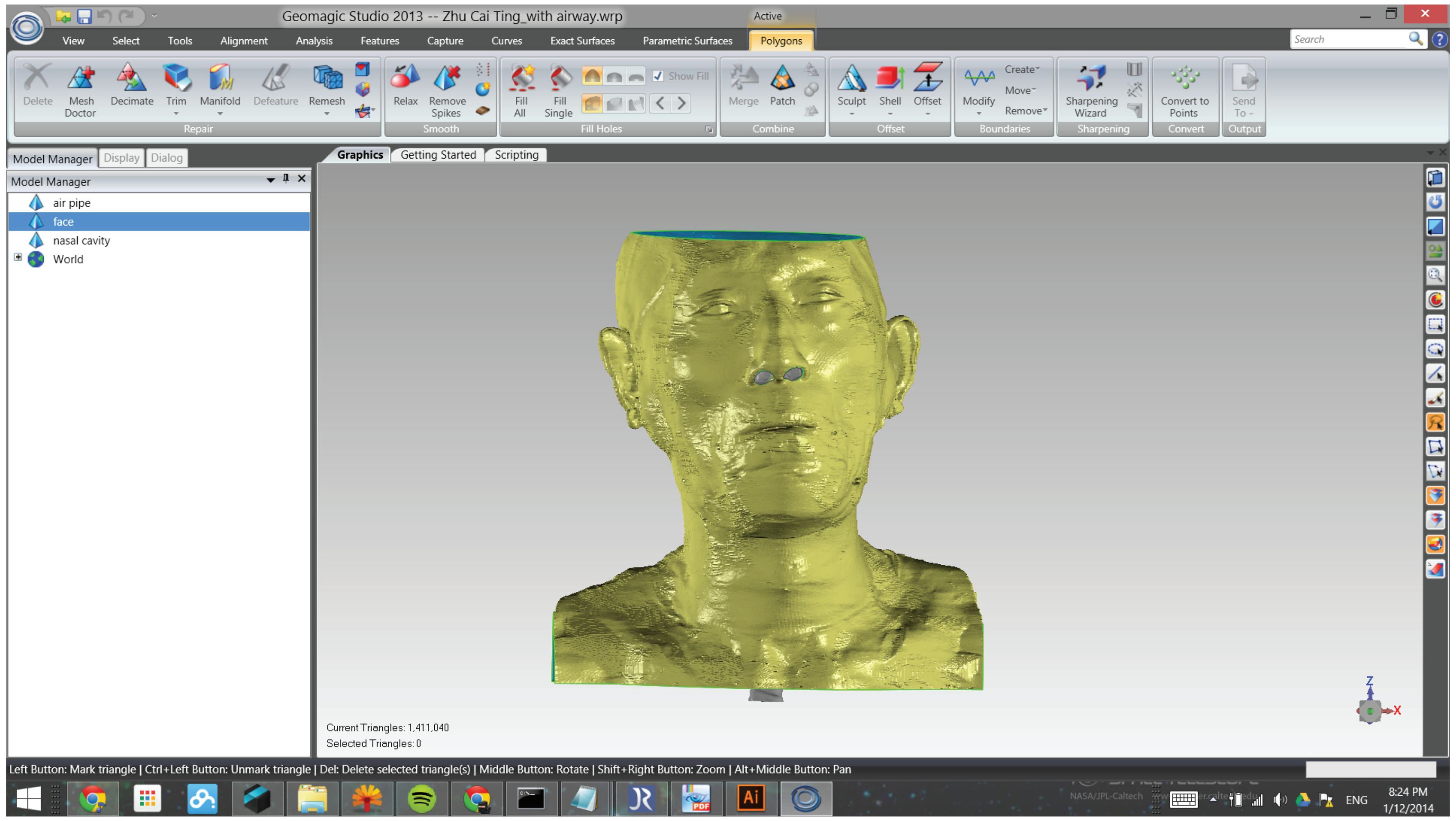
Geometry refinement

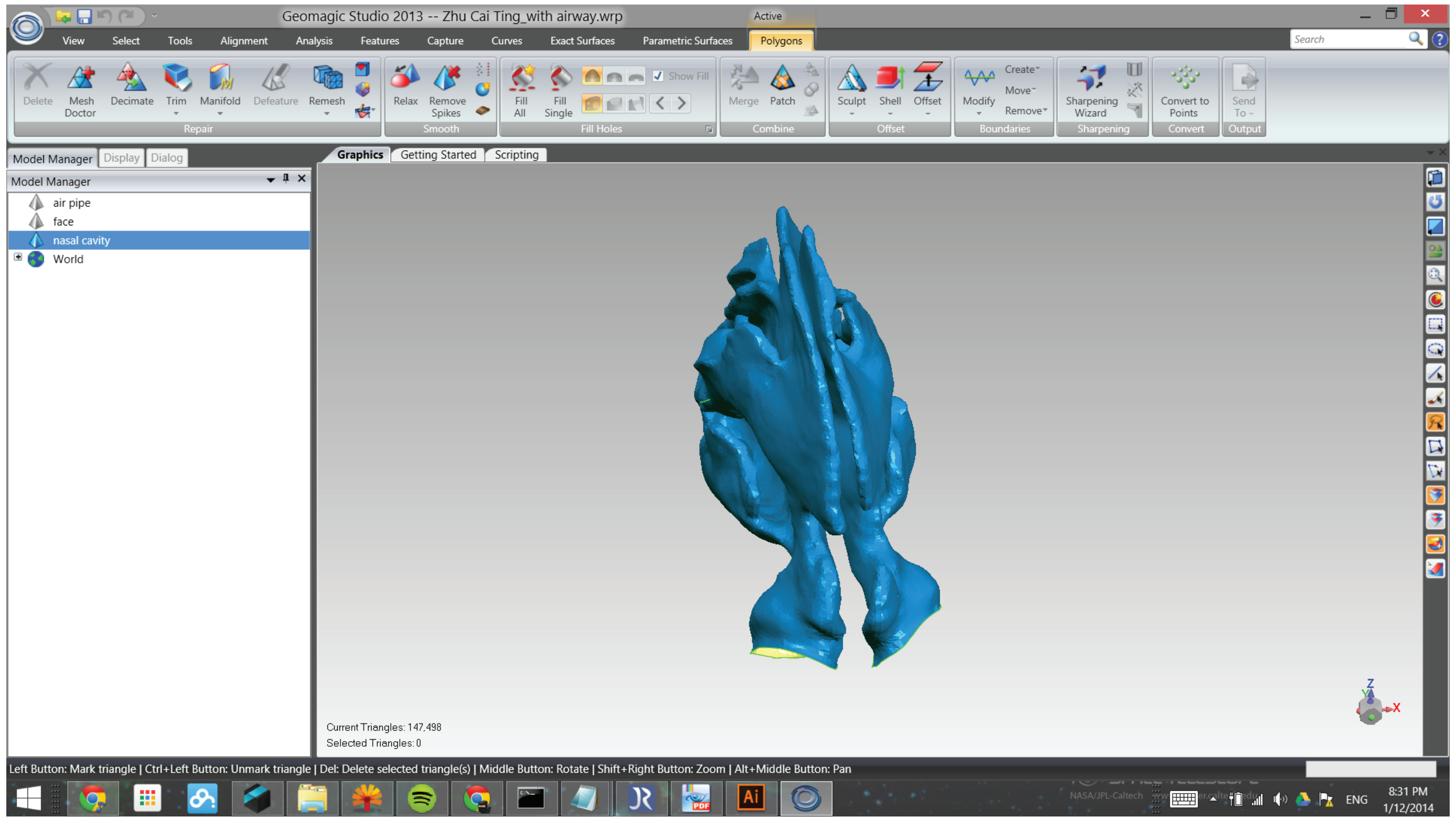
Geometry from mimics is very coarse

Further refinement required

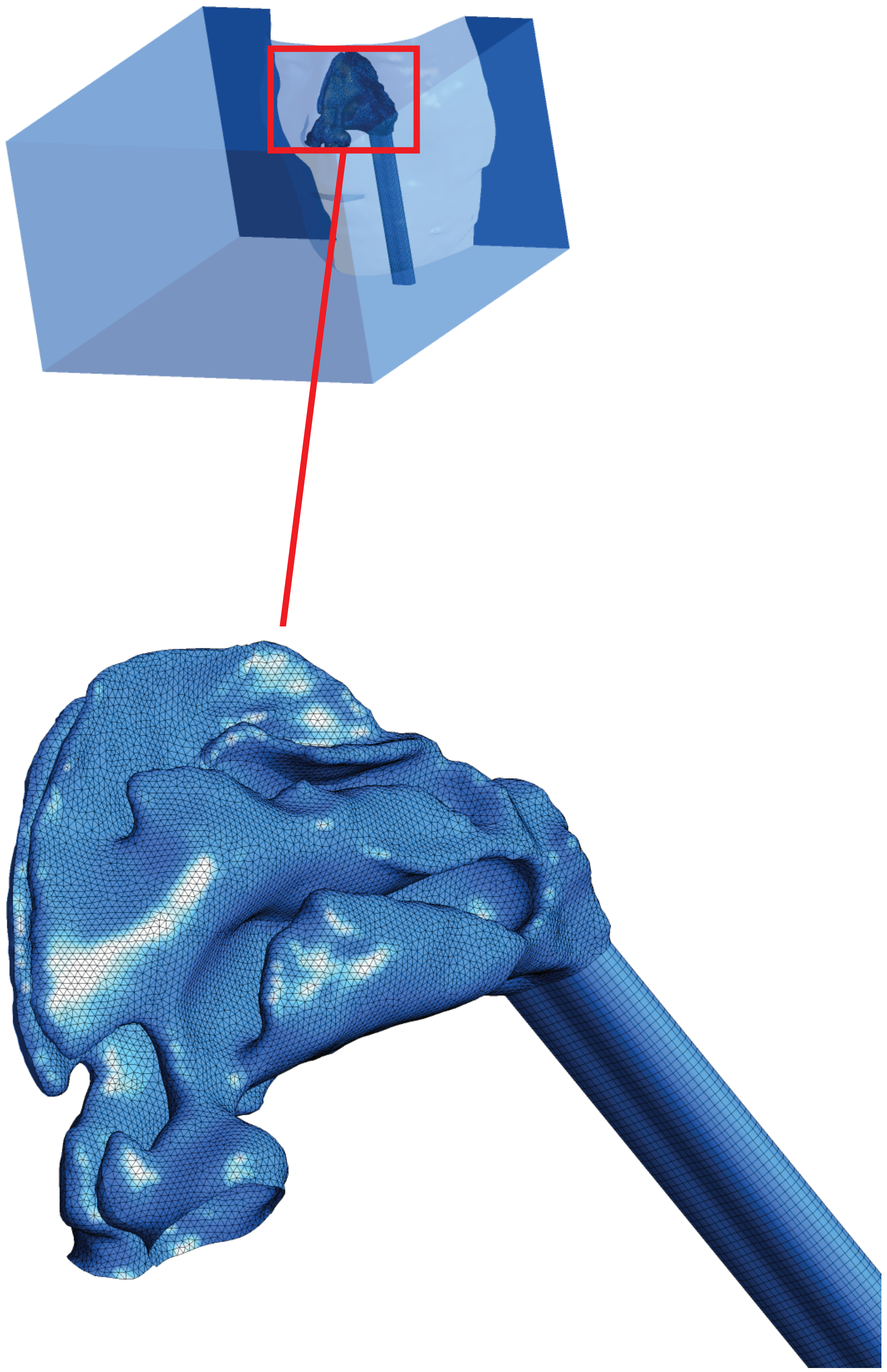
Geomagic used to refine the geometry for simulation

Face included to improve the accuracy of the inlet profile





Meshing



Unstructured tetra mesh

Box included for boundary conditions

Extension from outlet to simulate the trachea

Solving the governing equations

$$\frac{\partial}{\partial x_i}(\rho_g u_i^g) = 0$$

$$u_j^g \frac{\partial u_i^g}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p_g}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\nu_g \frac{\partial u_i^g}{\partial x_j}\right)$$

Used commercial code FLUENT

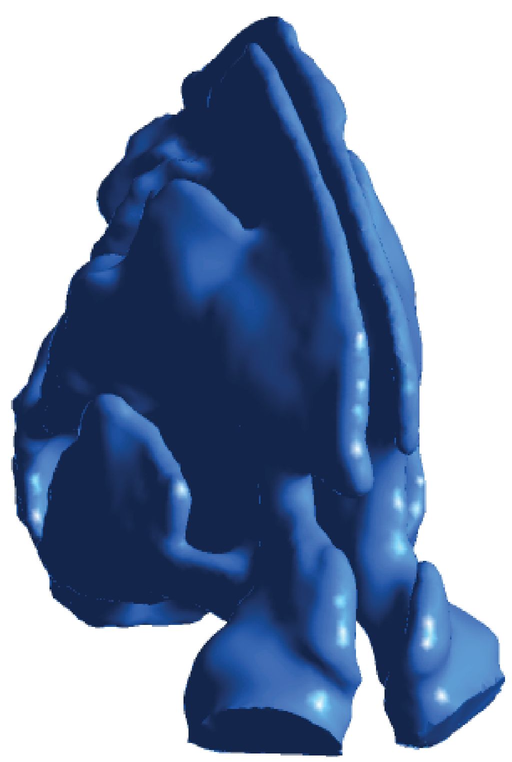
Two flow rates: resting and moderate

resting flow rate laminar

moderate flow rate employed transitional SST turbulence model

Geometric comparison

	Volume (cm3)			Surface area (cm2)			effective diameter (cm)		
	Elderly	*Young adult*	*%diff*	*Elderly*	*Young adult*	*%diff*	Elderly	Young adult	%diff
Turbinal region	21.73	17.58	23.62	150.70	142.66	5.64	0.58	0.49	14.54
Pharynx	5.40	3.84	40.39	12.80	12.20	4.97	1.69	1.26	25.23
olfactory	1.05	0.96	9.43	23.37	28.26	-17.30	0.18	0.14	24.42
vestibule	4.15	3.10	33.96	17.37	15.71	10.63	0.96	0.79	17.42
total	32.33	25.48	26.87	204.25	198.82	2.73	0.63	0.51	19.03



Elderly model

Young adult

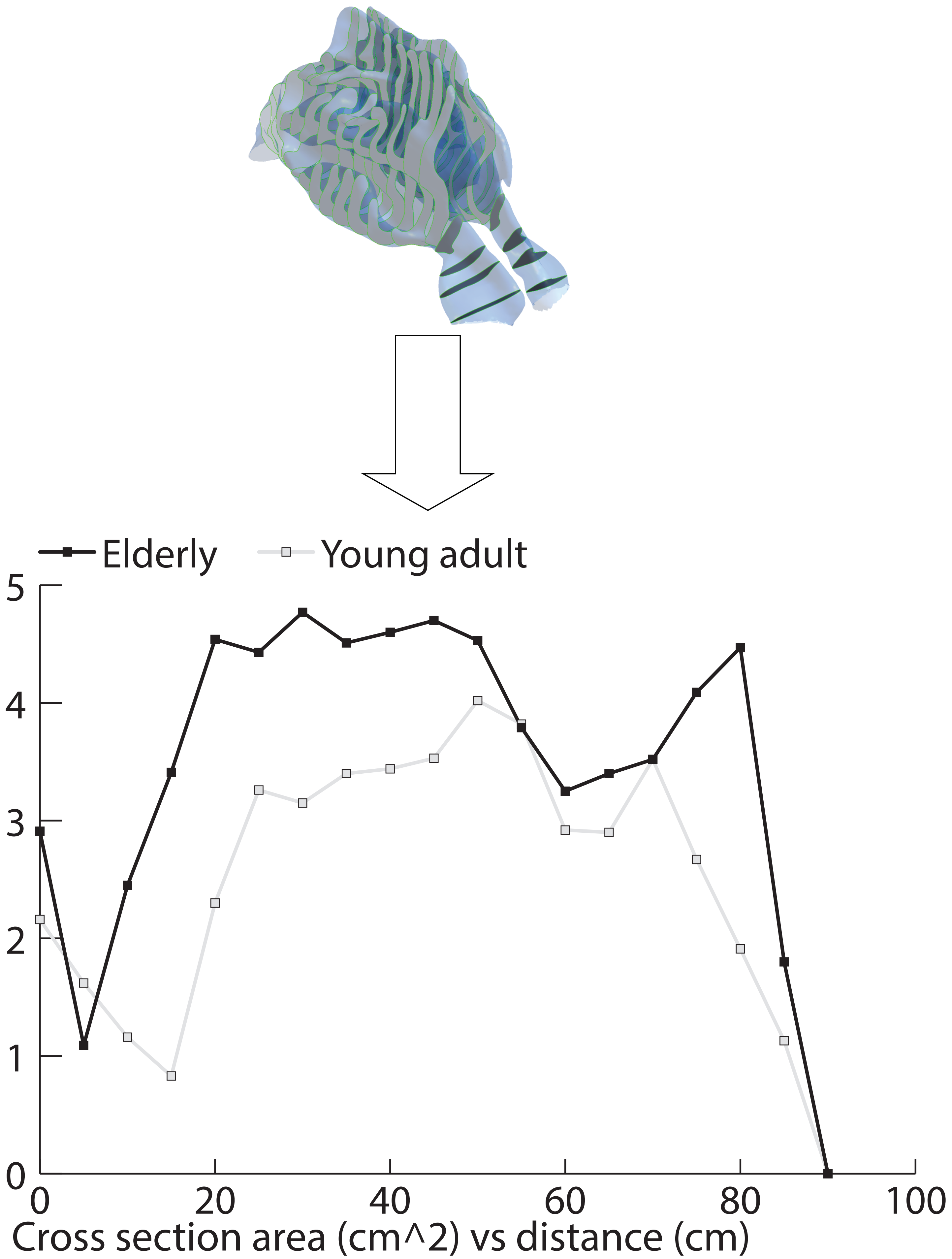
Interpretation.

AtrophIc rhinitis study also showed smaller surface area to volume ratio

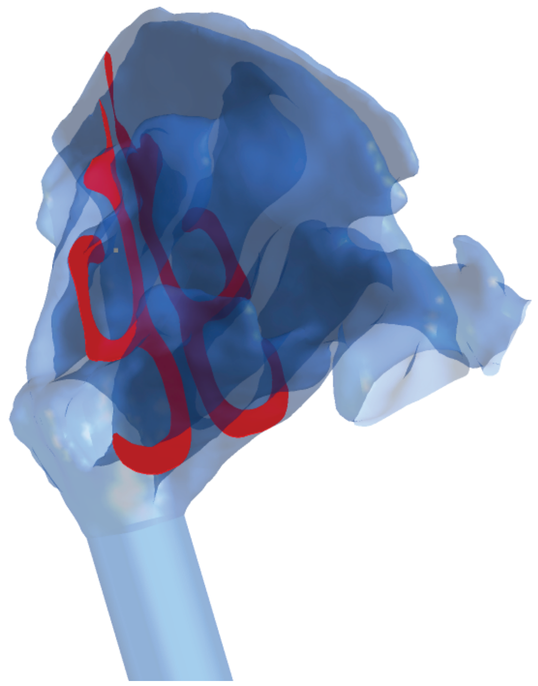
Less turbulence

Less heat/moisture transfer taking place

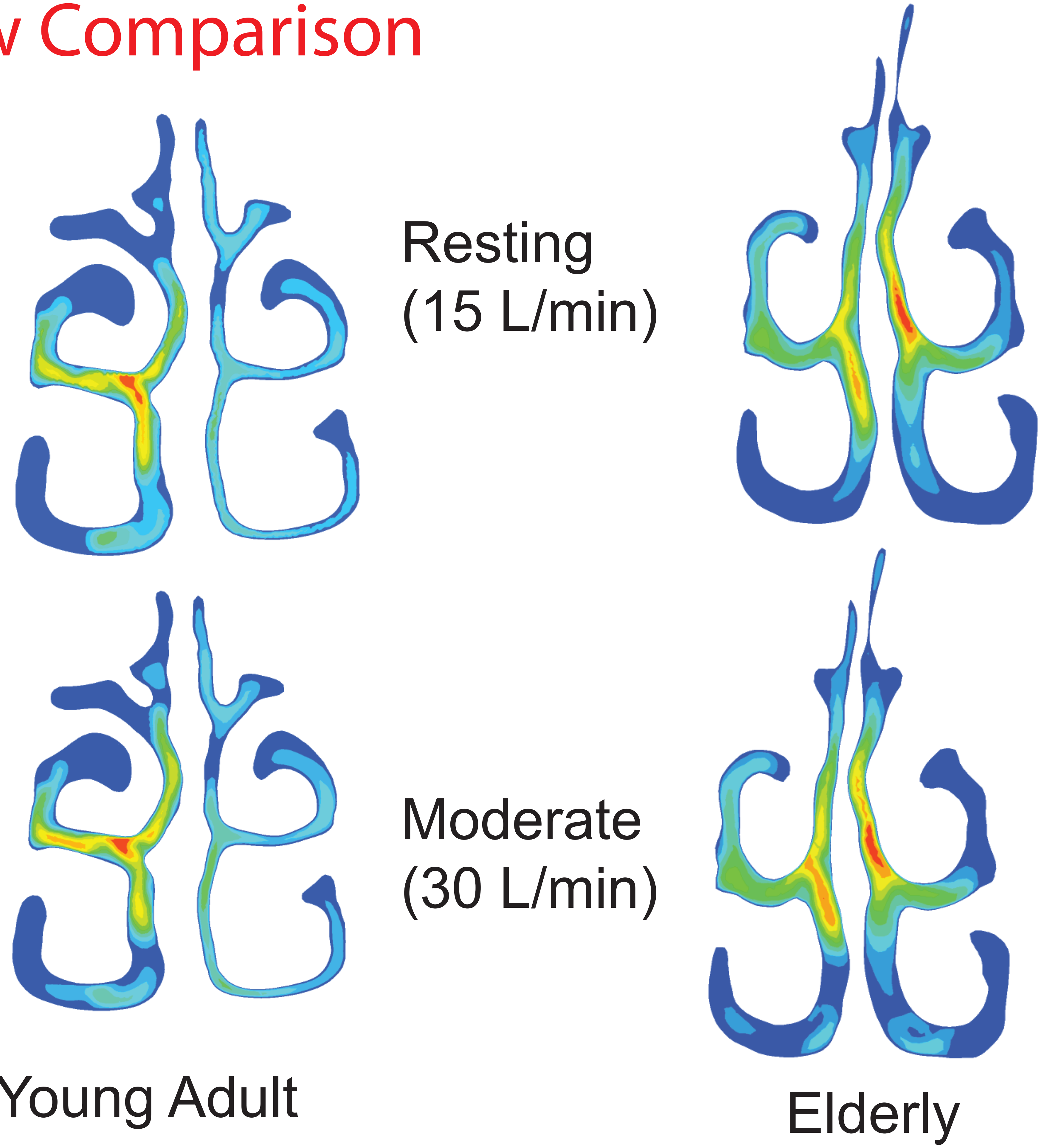
Smaller nasopharynx



Flow Comparison



Cross section location



Mid face coronal cross-sectional velocity contour of both models

Still to come...

- Results validification and analysis

- Air conditioning

- Air conditioning optimisiation

- Air conditioning comparison

Research plan

step no	title of activity	Description and relation to research questions
1	Literature review	Current literature will be reviewed as to establish the necessity of and context in which the research is taking place
2	Reconstruction of elderly nasal cavity	Nasal cavity of an elderly specimen will be reconstructed from CT scans for computational analysis, to provide a basis for the analysis
3	Meshing of model	The aforementioned geometries are then used to generate a computational mesh using ICEM
4	Solving of model	Once the mesh has been generated the fluid dynamics are solved for computationally with Fluent for a range of respiratory rates covering active and resting respiration. For rates below 20 l/m the flow is modelled as laminar[**?**] For higher flow rates the k-ω turbulence model with shear stress transport is applied[**?**]. This provides the basis for all further analysis
4.1	Validation of model	These models will be validated by comparison with the literature
5	Air conditioning models	Next the implementation of air conditioning models will be researched and implemented.
5.1	Validation with literature	The air-conditioning results will be validated by comparison with experimental results from the literature
5.2	Air conditioning model optimisation	The mesh and equations of the model will continue to be refined for better accuracy

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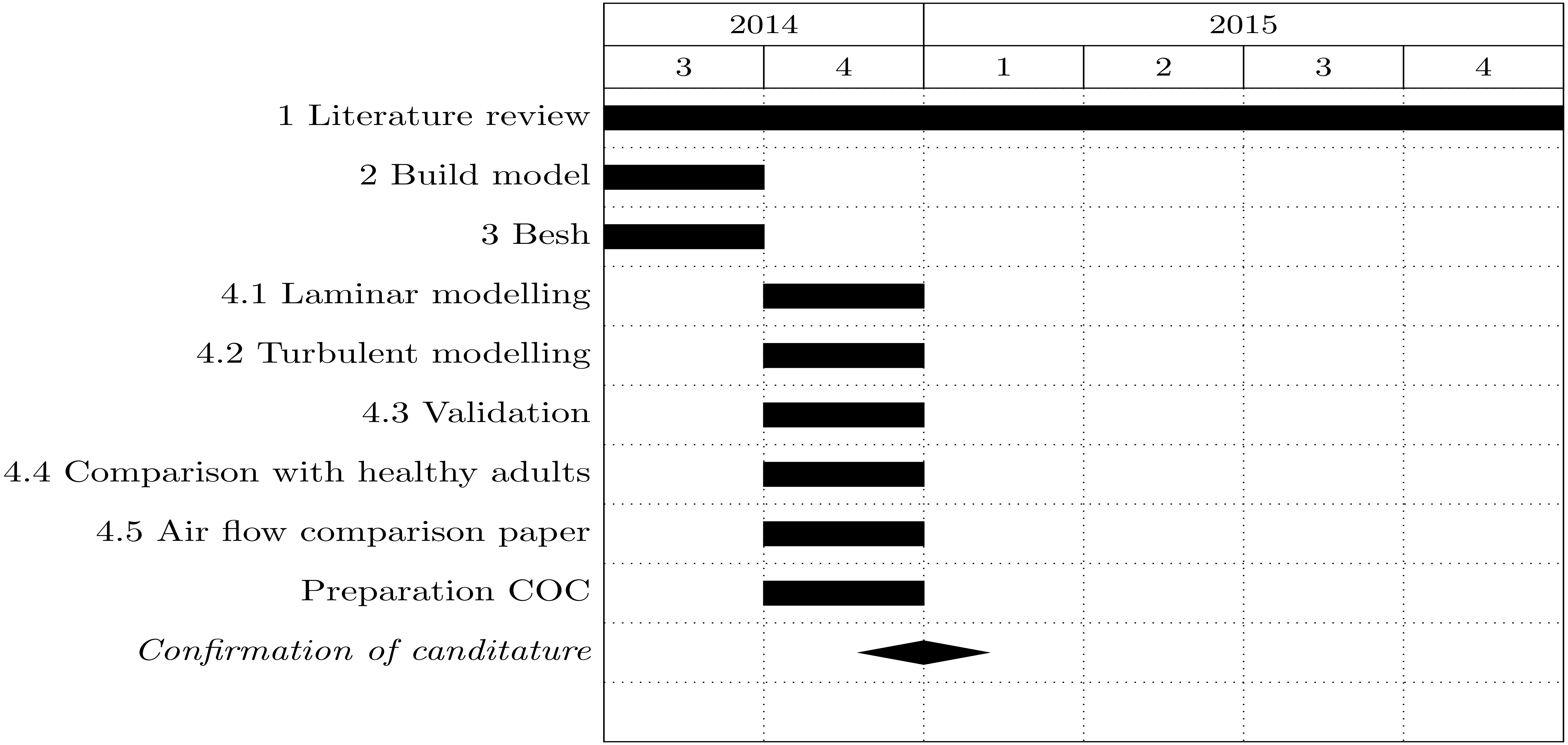
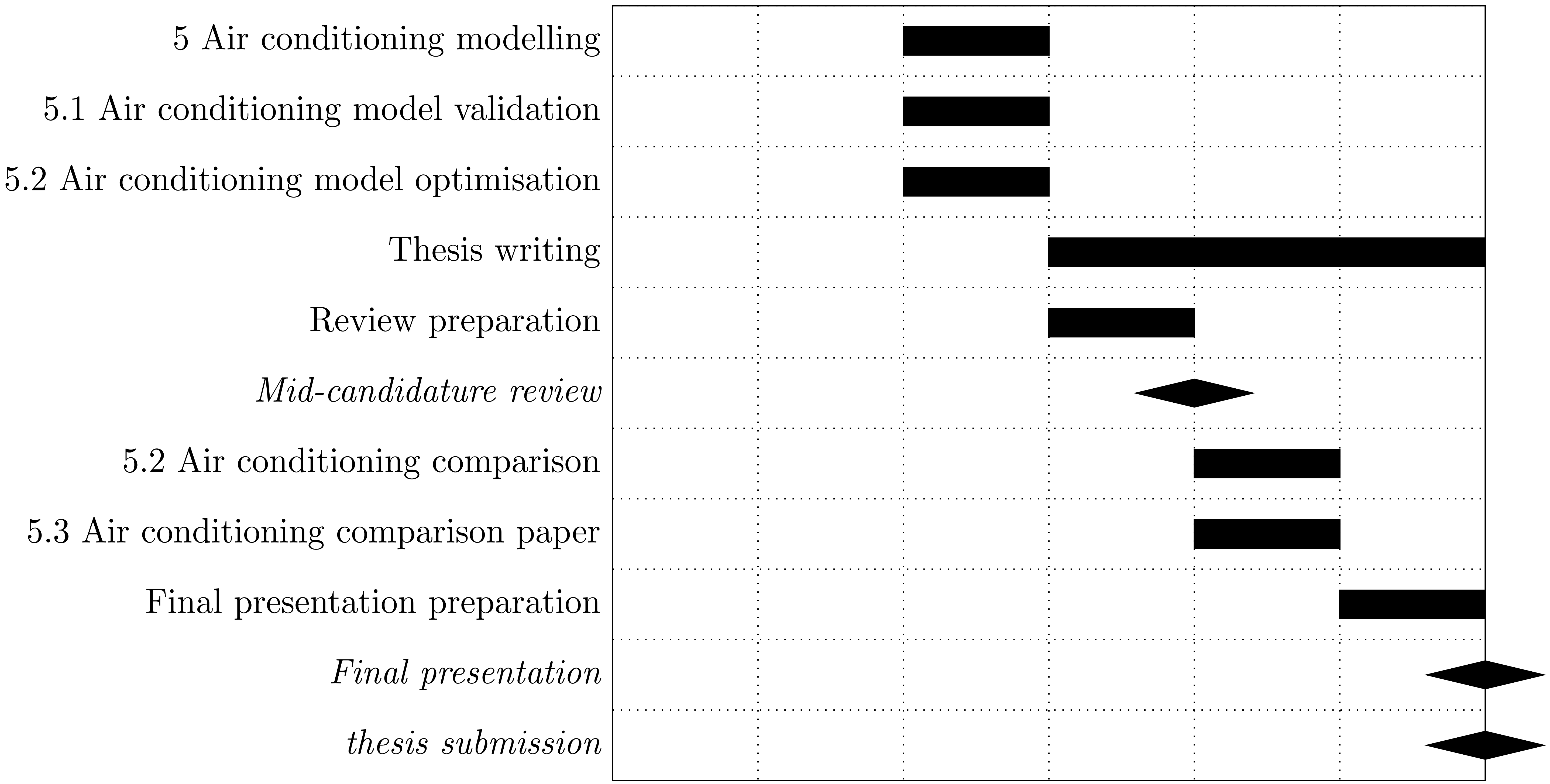
Gantt chart



2014
2015
3
4
1
2
3
4
1 Literature review
2 Build model
3 Besh
4.1 Laminar modelling
4.2 Turbulent modelling
4.3 Validation
4.4 Comparison with healthy adults
4.5 Air flow comparison paper
Preparation COC
Confirmation of canditature


5 Air conditioning modelling
5.1 Air conditioning model validation
5.2 Air conditioning model optimisation
Thesis writing
Review preparation
Mid-candidature review
5.2 Air conditioning comparison
5.3 Air conditioning comparison paper
Final presentation preparation
Final presentation
thesis submission

Thank you...

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