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converting 3D images into numerical models

Presented at the COMSOL Conference 2009 Milan

Image-based simulation of the human thorax for cardio-pulmonary applications

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Simpleware Ltd. (UK)

Presentation overview

Company

Software solution

Case Study

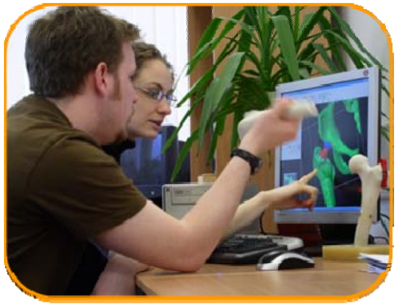
Conclusion

Company

Simpleware

Developers of world-leading image processing environment for the conversion of 3D images into numerical models

- Image-based meshing software and services for your research in:
  - Biomechanics
  - Materials
  - Natural Sciences
- Global customer base
- World-wide reseller network

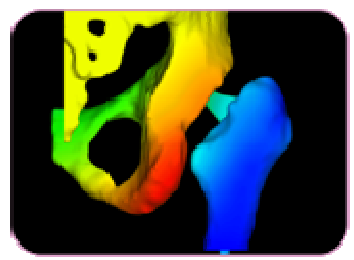
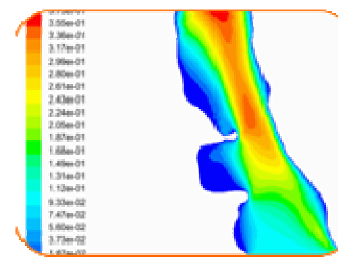


Simpleware Software

Automatic conversion of 3D images into high quality CAD models and meshes, which can be directly used for:

- Computer Aided Design (CAD)
- Rapid Prototyping (RP)
- Finite Element Analysis (FEA)
- Computational Fluid Dynamics (CFD)



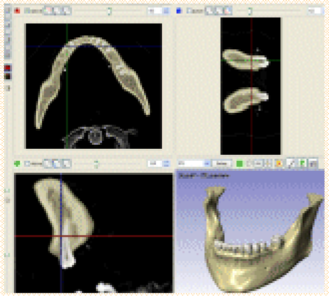



Direct approach - from scan to model

Scanning

ScanIP

Image processing



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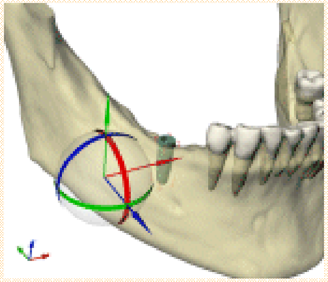
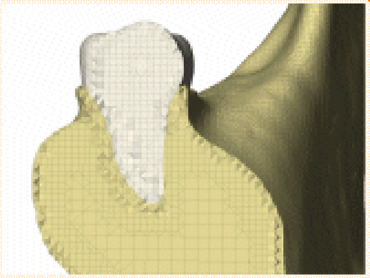
+ScanCAD

CAD import & positioning



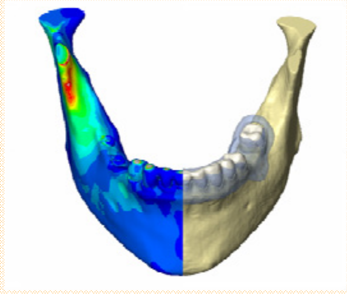
+ScanFE

Volume mesh generation

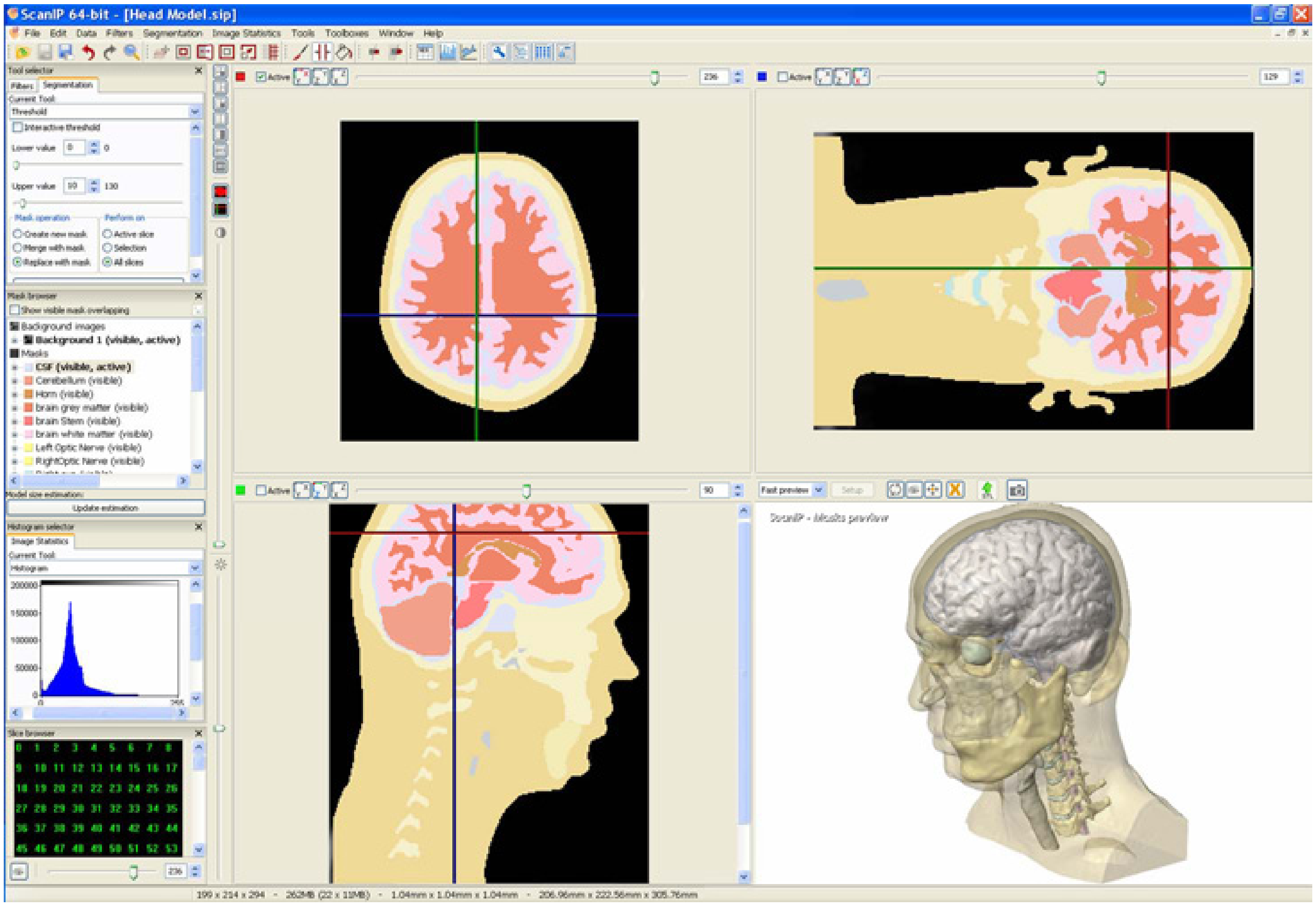


COMSOL

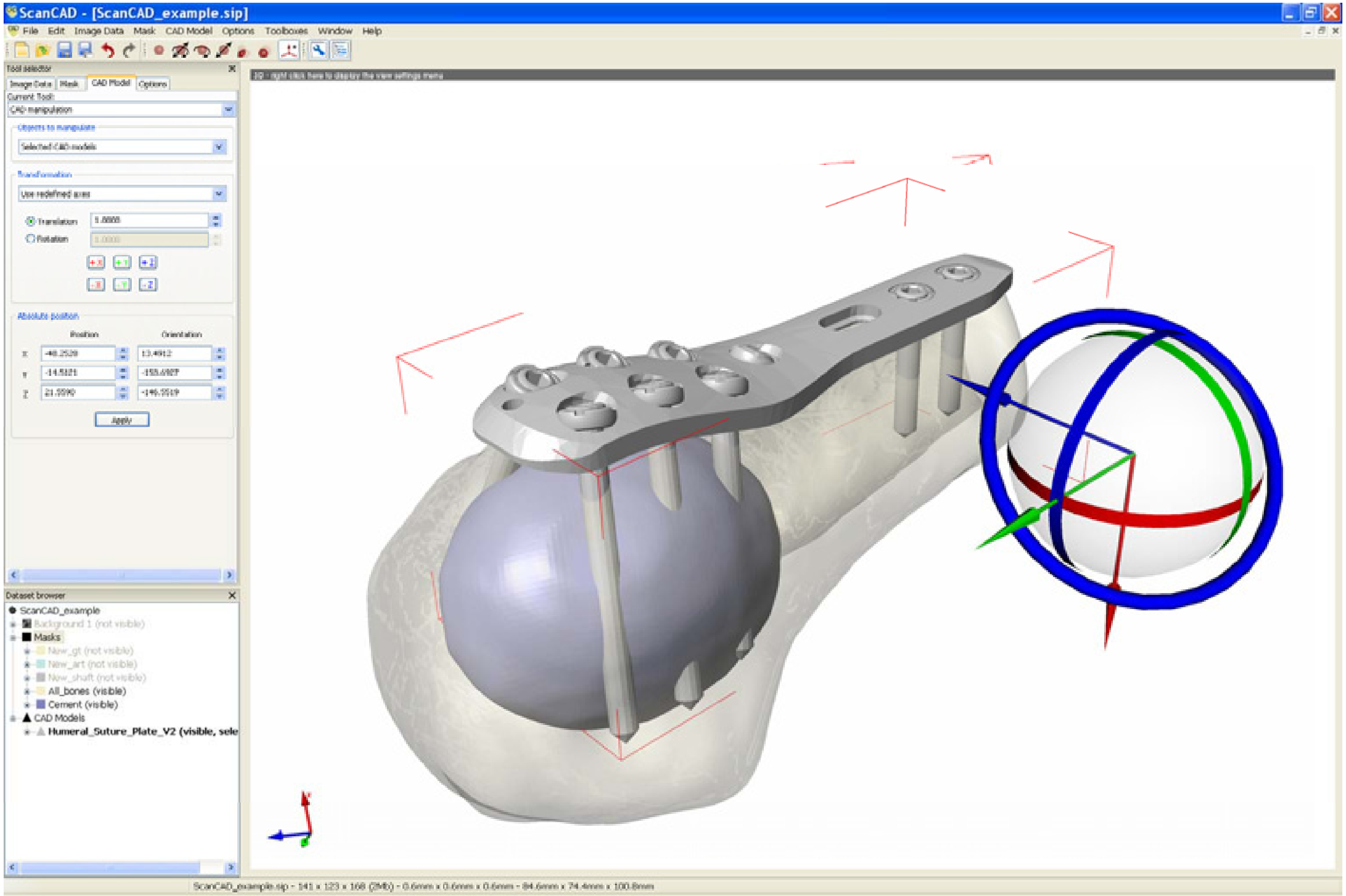
(CAD & FE/CFD)



ScanIP software
Image Processing/Segmentation



+ScanCAD module
Import and positioning of CAD data



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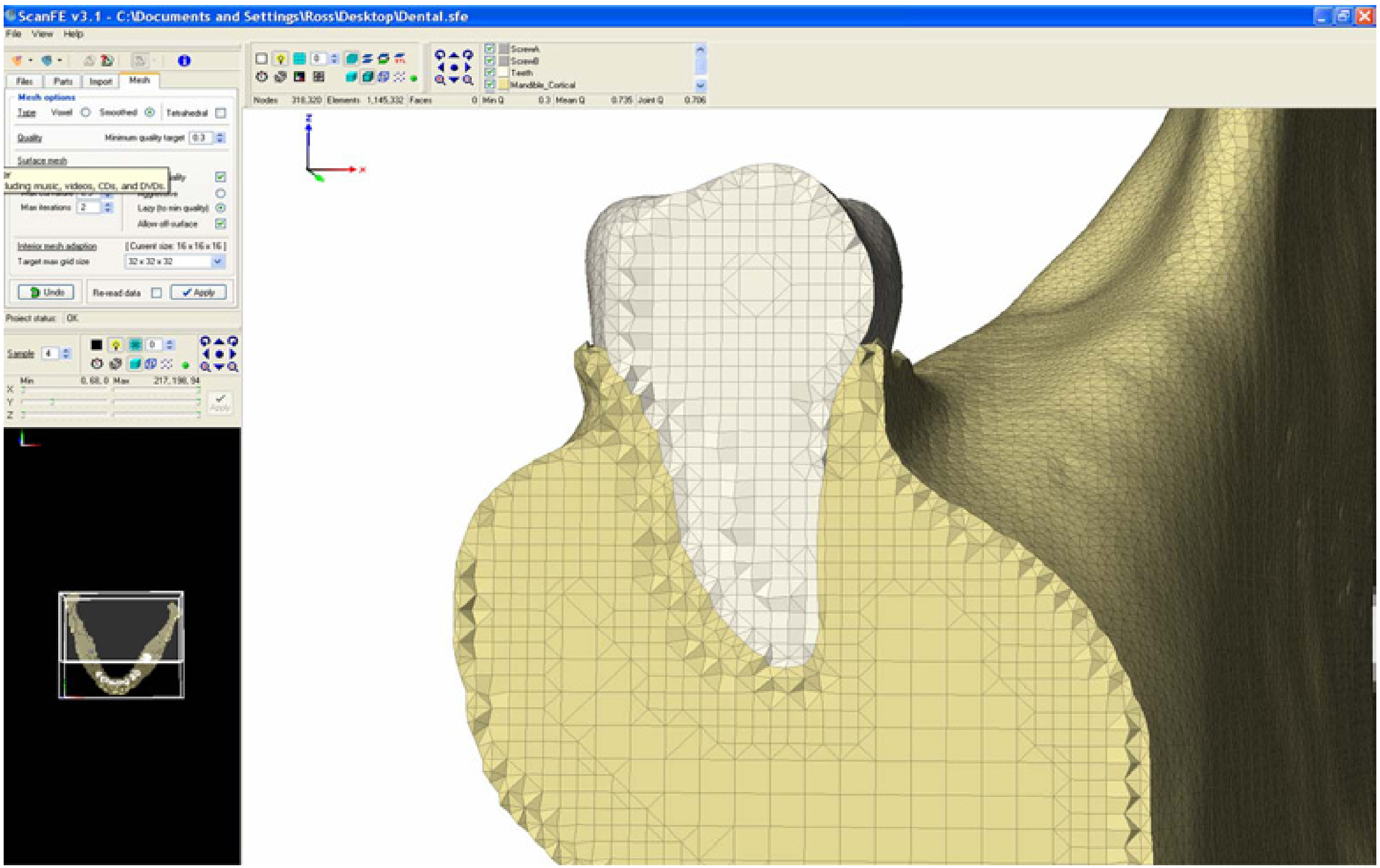
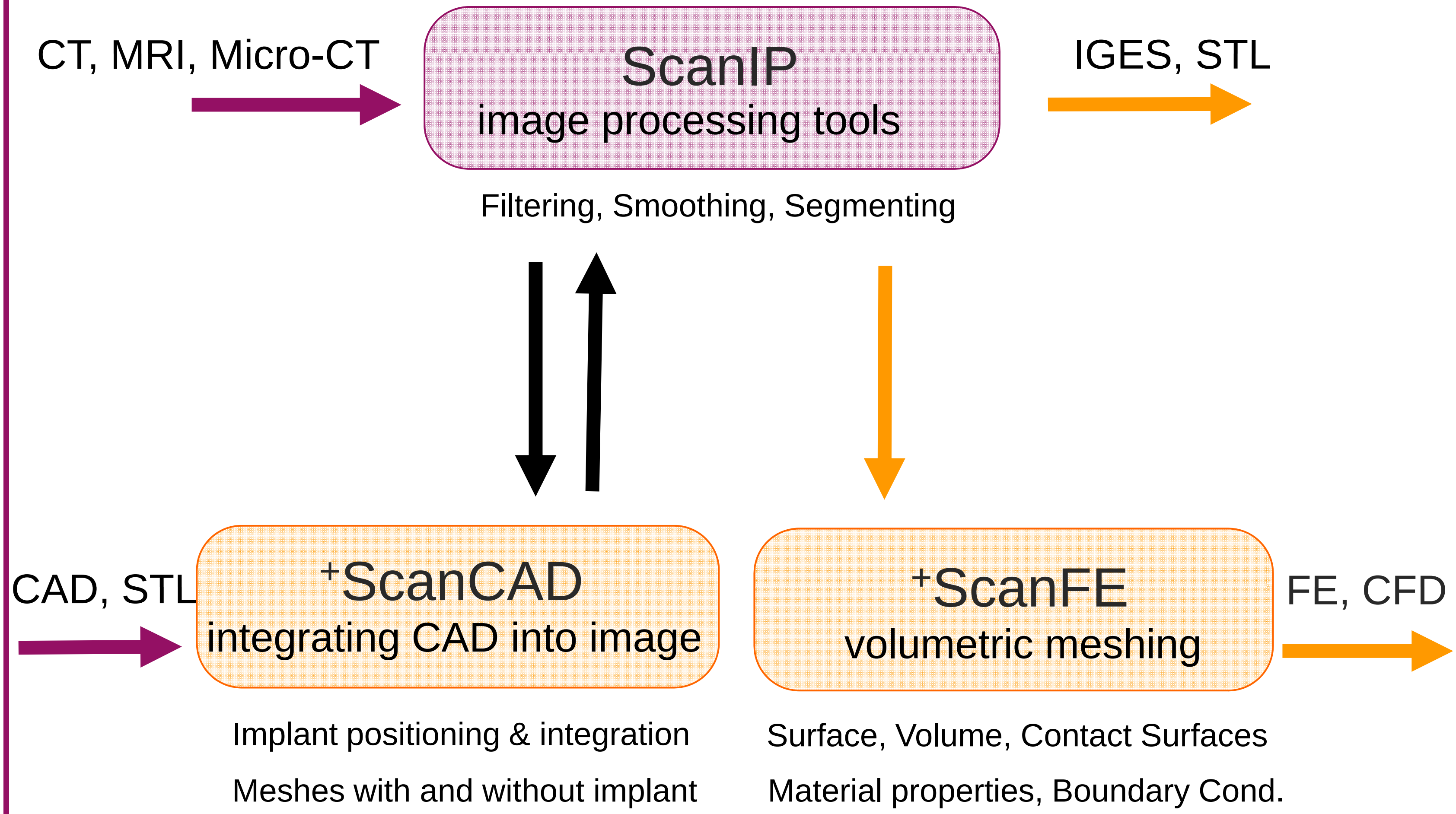
+ScanFE module
FE/CFD mesh generation



Simpleware - Software Integration



Case Study

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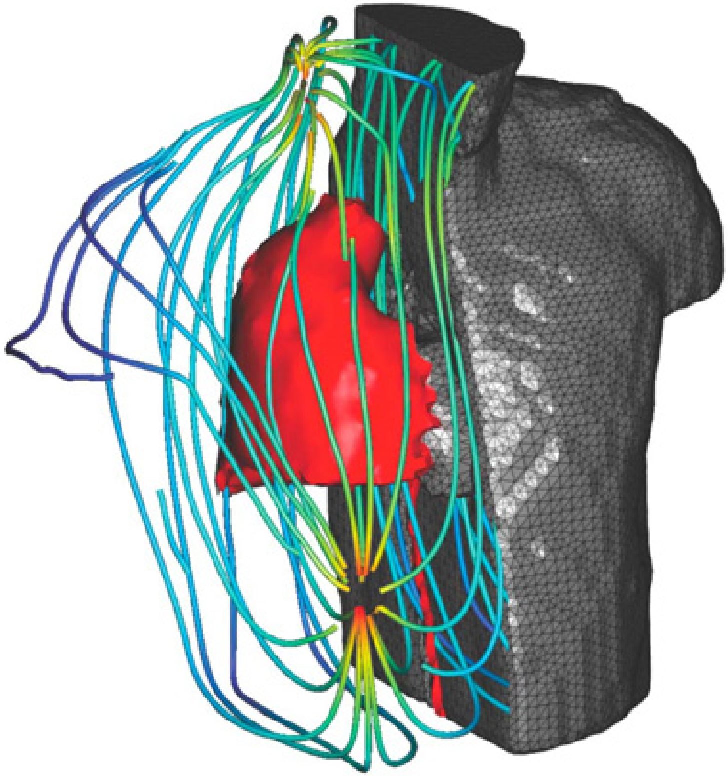
Human thorax for cardio-pulmonary applications



Introduction

- For medical diagnostic purposes there is an increasing need for non invasive techniques to measure all kinds of parameters that can provide insight in the functioning of cells, organs or organ systems
  - Amount of blood that is ejected by each cardiac contraction (stroke volume)
  - Functioning of the lungs during normal breathing or artificial ventilation.
- This study focuses on calculating the current distributions for ICG and EIT in models of the human thorax.
  - Impedance Cardiography (ICG)
  - Electric Impedance Tomography (EIT)

Methods

- Impedance Cardiography (ICG).
  - Small, harmless alternating current is injected into a patient.
  - The current distributes through the thorax, and resulting voltages are measured with additional electrodes on the thorax.
  - If the heart contracts the diameter of the aorta increases. Its electrical impedance changes as well and changes in voltages at the skin occur..
- Electric Impedance Tomography (EIT)
  - To measure the filling of the lungs with air, a ring of electrodes is attached to the patients thoracic skin
  - Two neighbouring electrodes inject a small alternating current; resulting voltages are measured at all other 13 adjacent electrode pairs.
  - From these measurements one tries to reconstruct the impedance distribution in the electrode plane. As lungs, muscles, blood etc. have different impedances the reconstructions provide information about tissue distribution in the cross-section of the patient.

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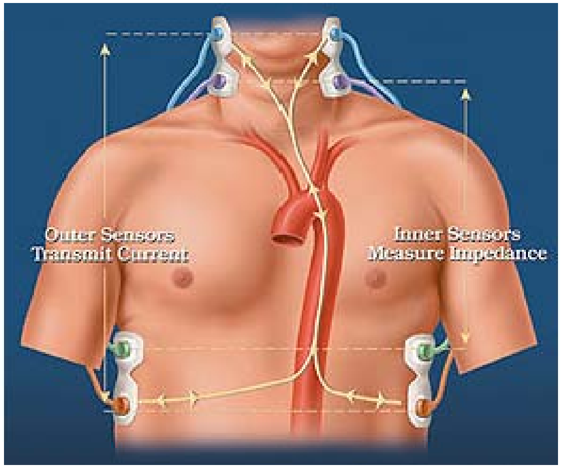
Method

How ICG Works:



- An alternating current is transmitted through the chest.
- The current seeks the path of least resistance: the blood filled aorta.
- Baseline impedance to current is measured.
- Blood volume and velocity in aorta change with each heartbeat.
- Corresponding changes in impedance are used with ECG to provide hemodynamic parameters.

- Create a FE model to determine which part of total electrical current flows Heart, lungs and Aorta.
  - In ICG and EIT.
  - Effect of geometry changes due to
    - Breathing and cardiac contraction
    - Bone Structure

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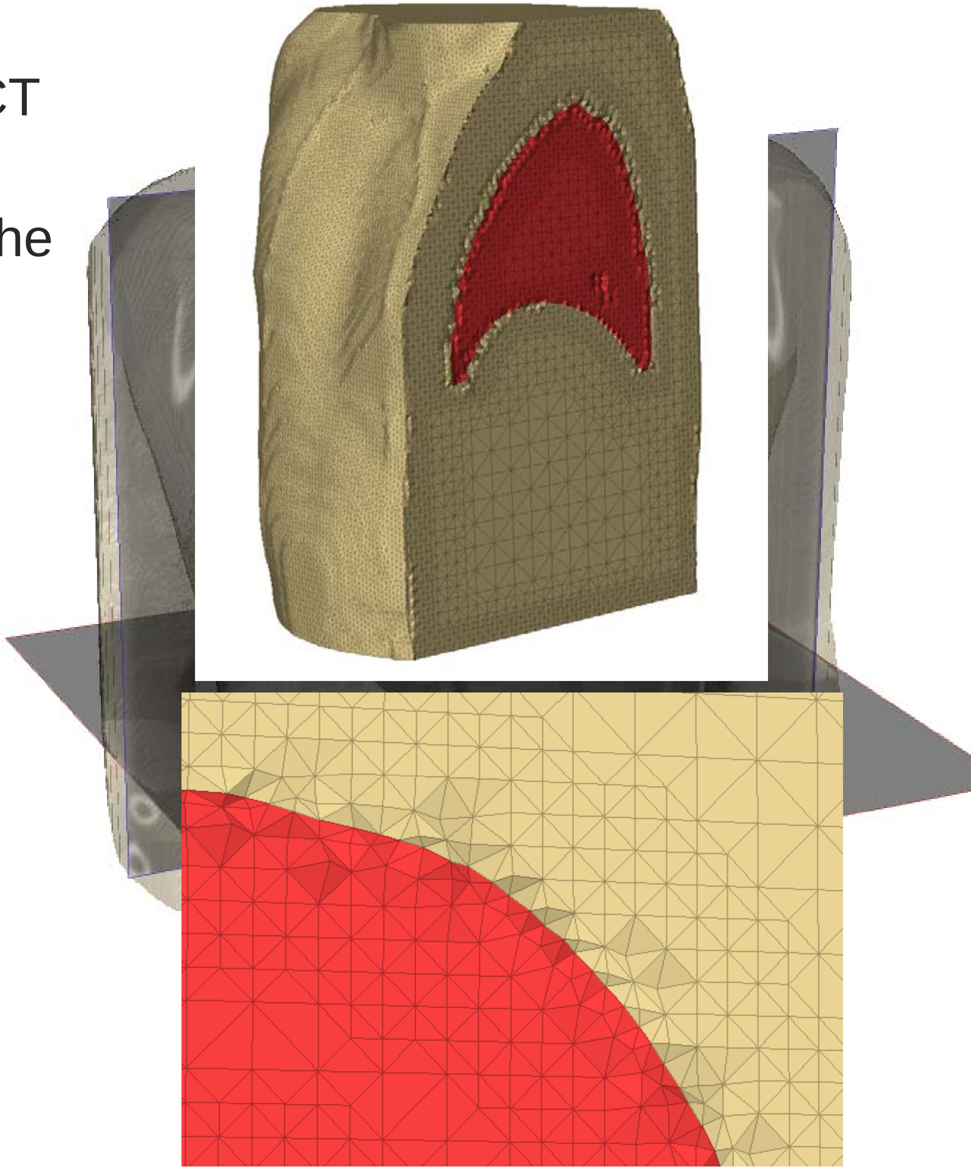
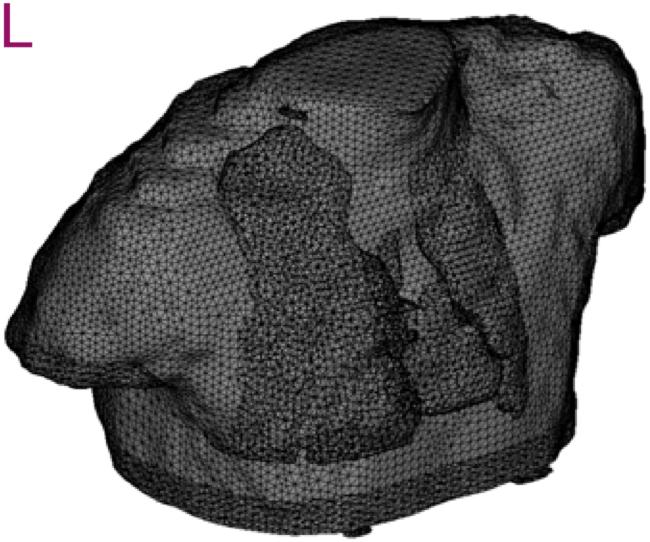
Method: Simpleware generated Finite Element Model

- Import image data from CT or MRI
- Use ScanIP to segment the regions of interest
  - Lungs
  - Aorta
  - Heart
- ScanFE mesh after smoothing, consisting of 173,986 elements with electrodes
- Segmented regions form sub-domains within COMSOL

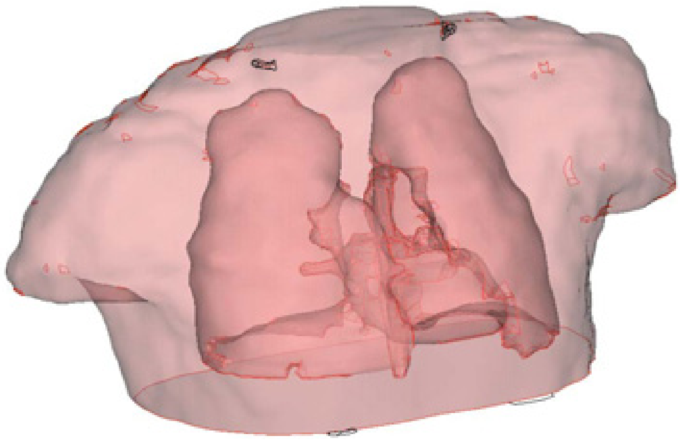


Exported FE Mesh in COMSOL

- Current flow through each organ
- Integrated the total current density over volume of each individual organ
- The current flowing through each organ is calculated as a percentage of the total current flowing through the plane.



The FEM mesh



Subdomain settings: electrical resistivities

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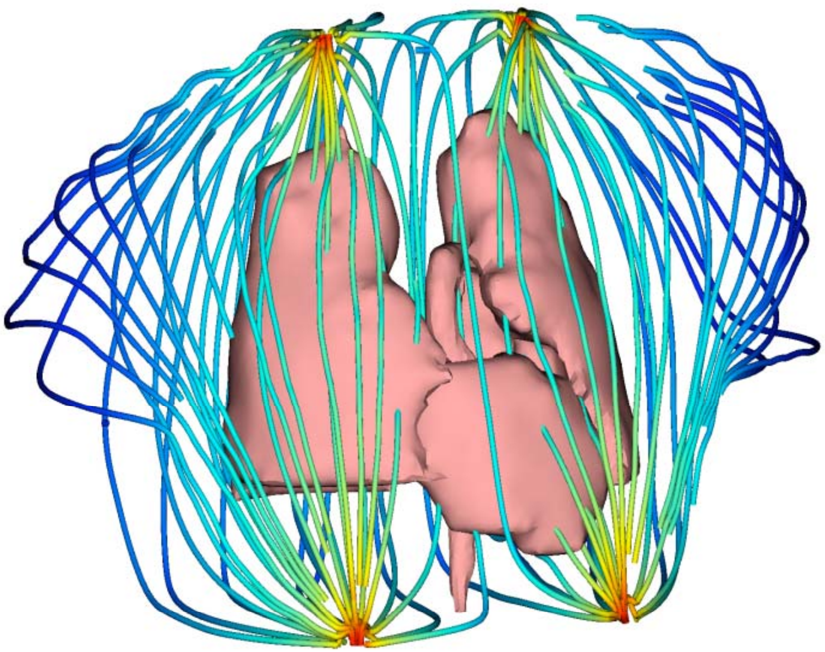
Results

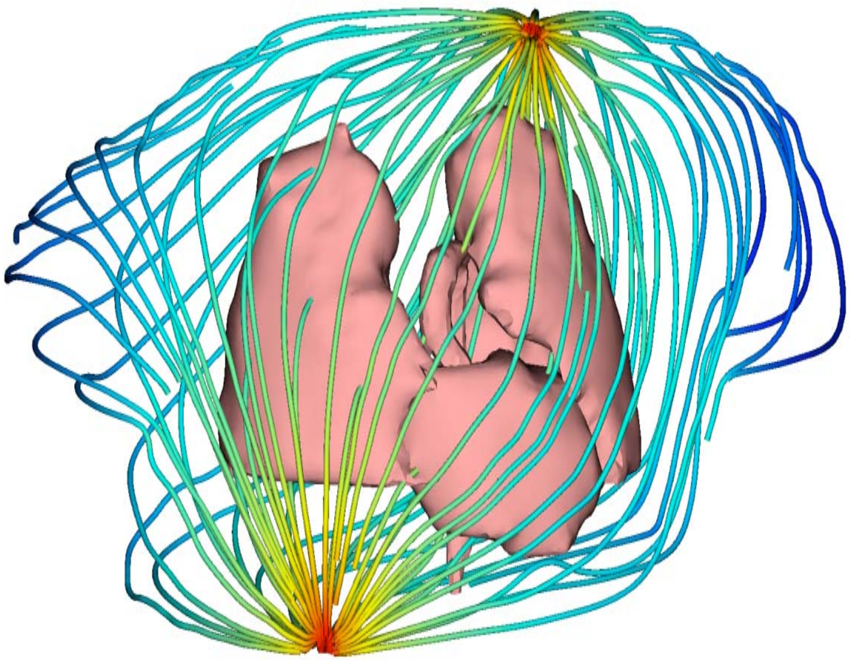
- FEM solution of the four current electrode setup



  - The streamlines are magnitude controlled:
  - Distance between adjacent streamlines is related to the local current density.
  - The colour of streamlines is logarithmically related to the local current density

Results

- FEM solution of the two current electrode setup



  - Electrical current streamlines are quite widely distributed through the thorax

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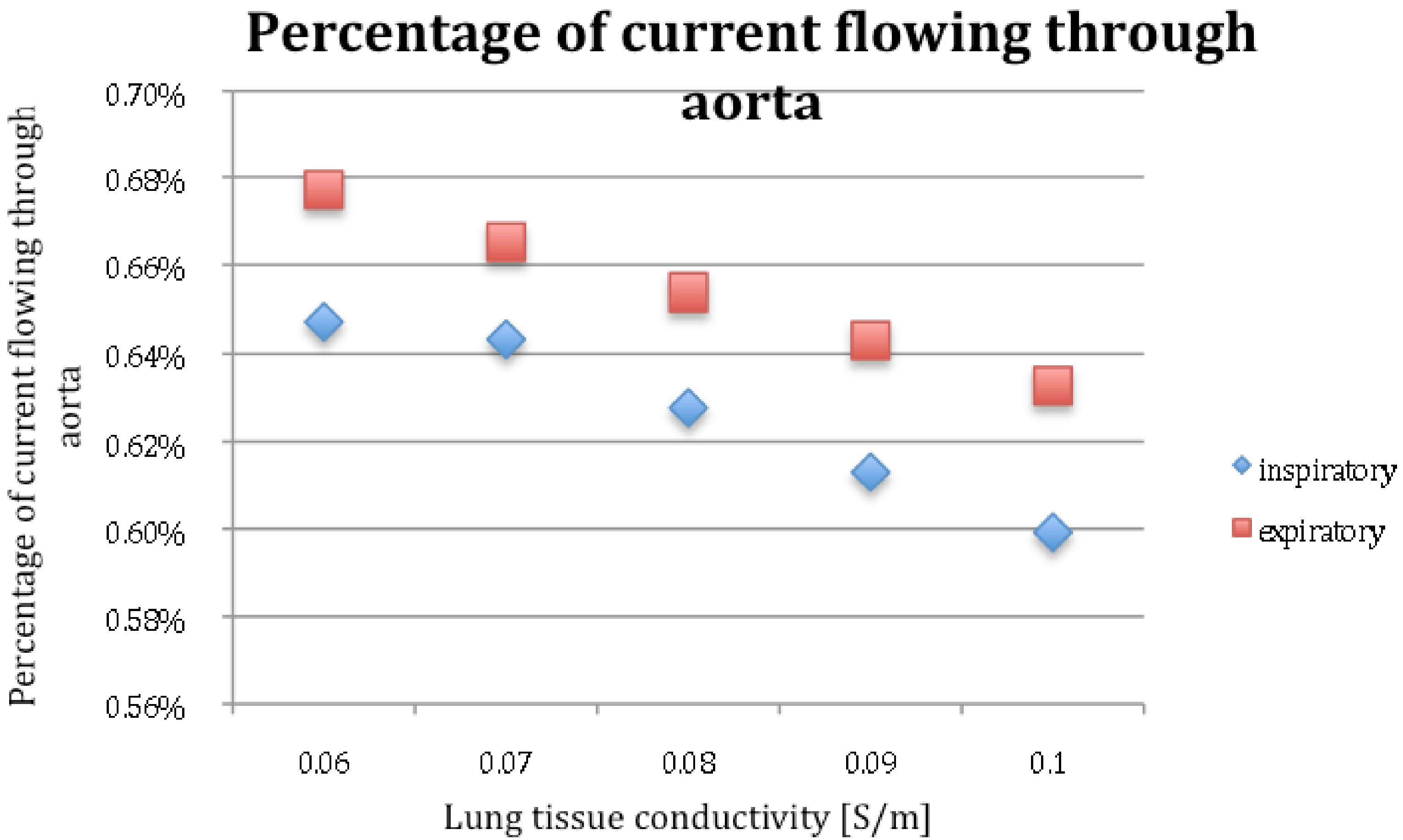
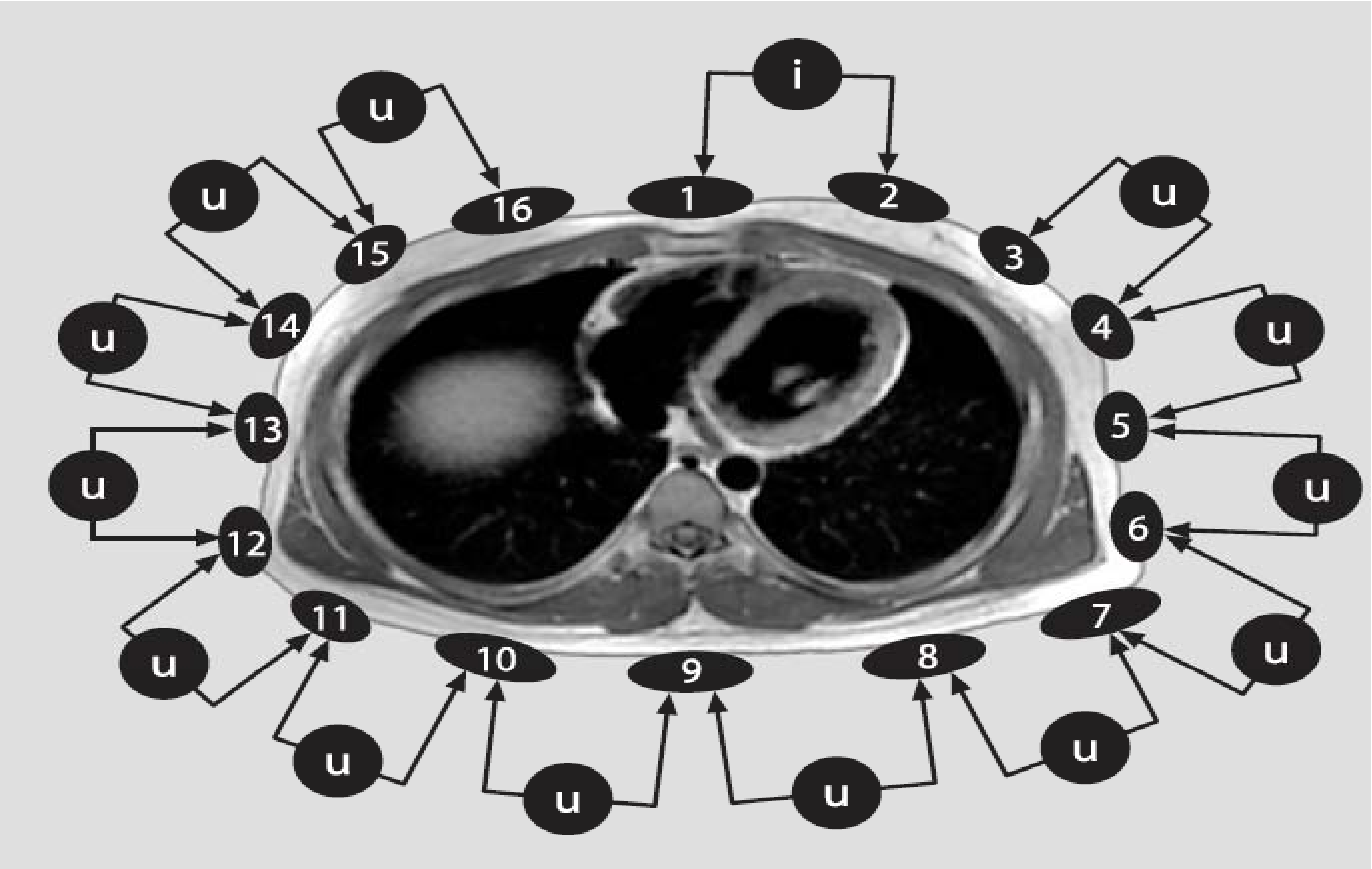
Results



Percentage of current through lungs, expiratory and inspiratory state, with different lung tissue conductivities, (VUmc MRI dataset)

FE for Electrical Impedance Tomography (EIT)



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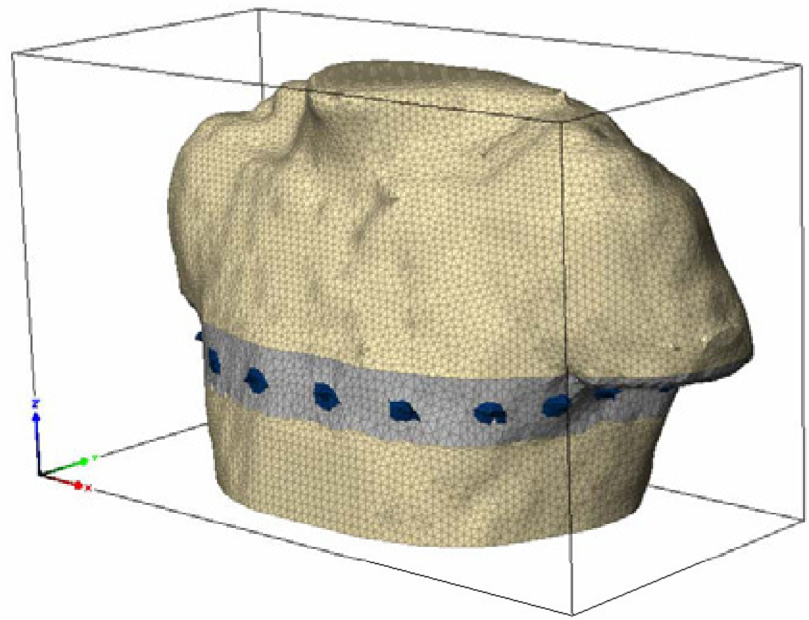
Simpleware generated Finite Element Model for EIT

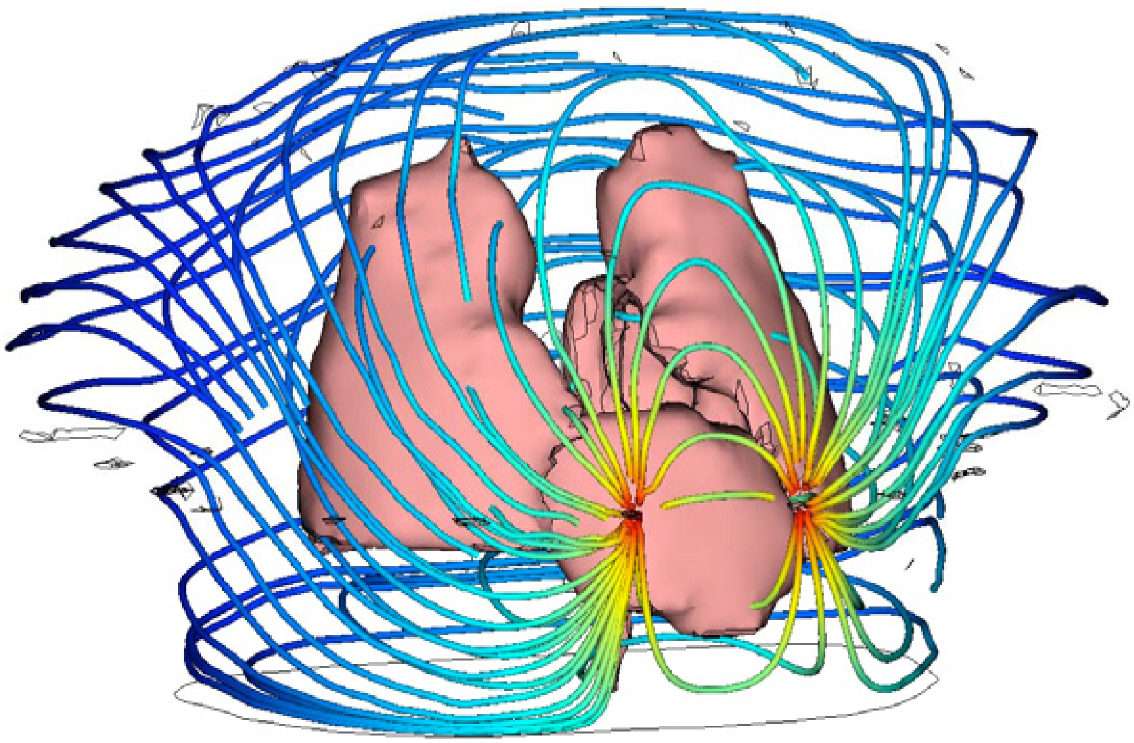
- ScanIP: the 16 electrodes are drawn around the thorax in the segmentation process.
- +ScanFE: generates the volume mesh
- Import the mesh in COMSOL (*.mphtxt)
- The electrode subdomain is disactivated; only the points from the electrode subdomain remain.
- These points are used to inject electrical currents of 5 mA.



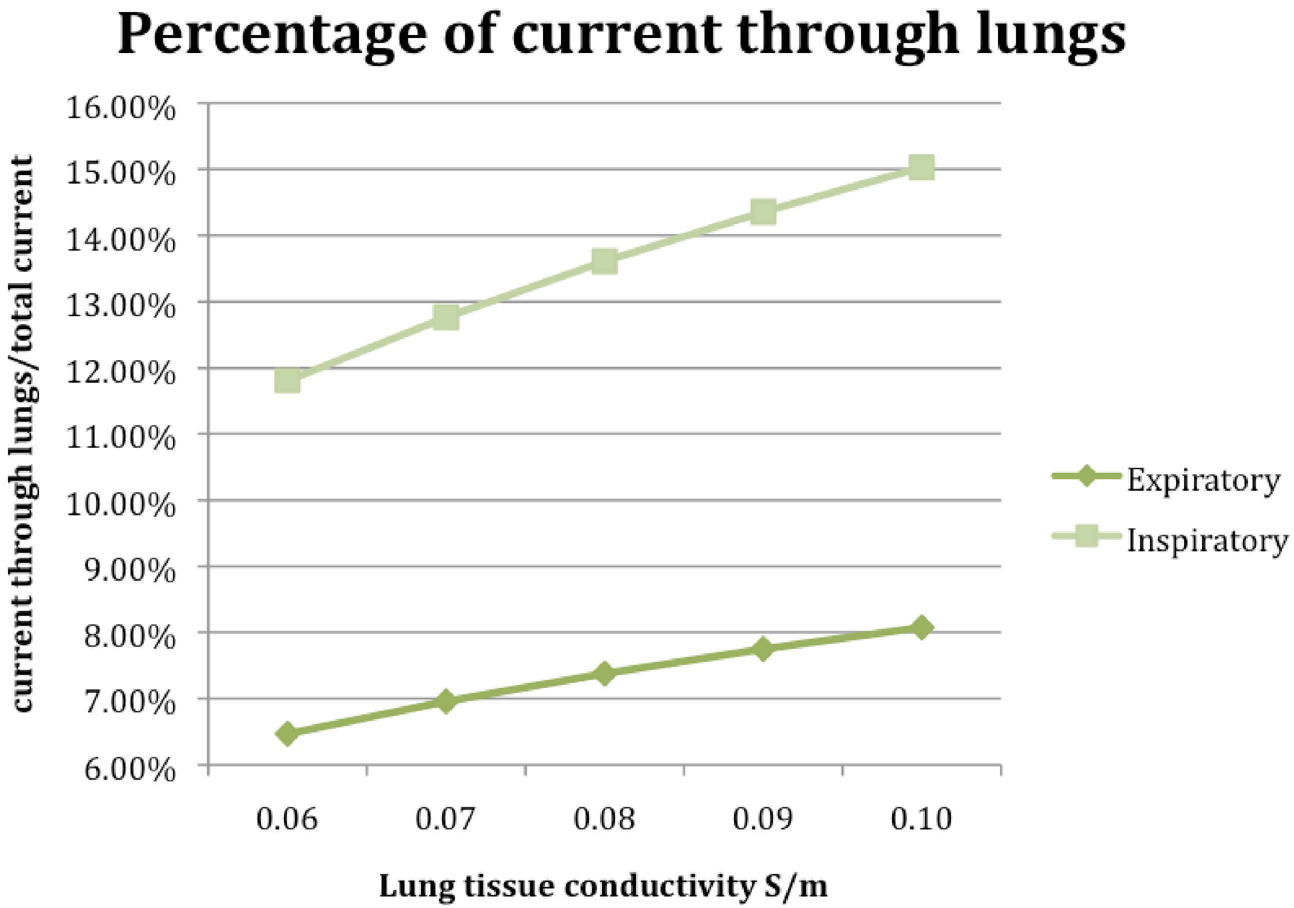
Electrodes on the outer boundary of the
3D FEM geometry

Results

- Influence of Breathing and Cardiac Cycle



Results



Electrical current distribution through the lungs as part of the total current as a function of lung tissue conductivity in an FEM modelled EIT experiment

Conclusions

Conclusion

Developed FEM models deliver interesting insight in the current Distribution throughout the upper thorax.

FE based modelling showed that greater part of electrical current Density is not concentrated in the aorta as stated by commercial ICG device producers but widely distributed throughout the thorax.

Although 2D experiments showed that influence of ribs did not Alter the current distribution through the organs significantly the Model would be more realistic when bone structure could be taken Into account to explore 3D situation.

Using image based meshing you can…

- …generate **straightforwardly** and **rapidly accurate models** for simulation/analysis - allows image processing to move beyond descriptive/statistical analysis of data
- …mesh **any number of structures** simultaneously (handles multi-part junctions) and **define contact surfaces** between them - interfaces are without gaps or overlaps.
- …generate coupled finite element and finite volume meshes for **multi-physics** applications
- …**incorporate designs** in the image data – predict and compare the performance of different designs

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