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converting 3D images into numerical models

Presented at the COMSOL Conference 2009 Boston

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

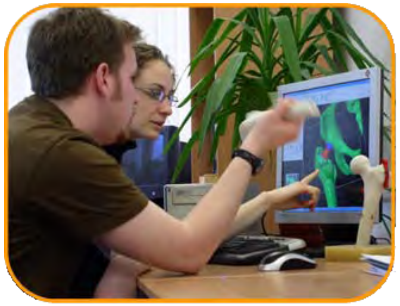
Conclusion

Company

Simpleware

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

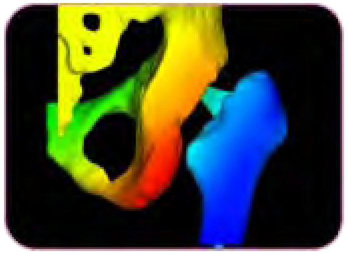
- Image-based meshing software and services for your research in:
  - Biomechanics
  - Materials
  - Natural Sciences
- Global customer base
- World-wide reseller network

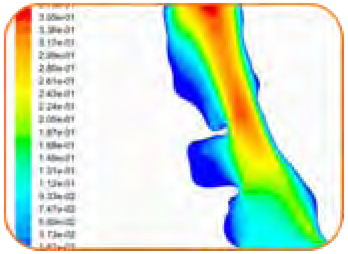


Simpleware Software

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)





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Selected Partners and Customers

COMSOL

SIEMENS

stryker

FhG Fraunhofer Gesellschaft

ARUP Oasys LS-DYNA

MANCHESTER 1824

NATURAL HISTORY MUSEUM

Imperial College London

NPL National Physical Laboratory

University of BRISTOL

UNIVERSITY OF CAMBRIDGE

ANSYS FLUENT

UNIVERSITY OF BATH

UNIVERSITY OF EXETER

3DS SIMULIA

Cleveland Clinic

NAFEMS

NASA

DELCAM www.delcam.com

CARDIFF UNIVERSITY

TechNetAlliance

Direct approach - from scan to model

Scanning

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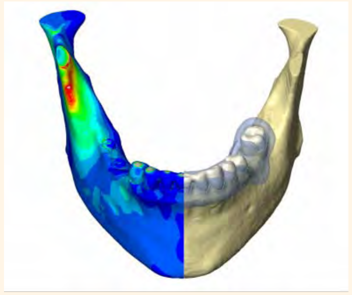
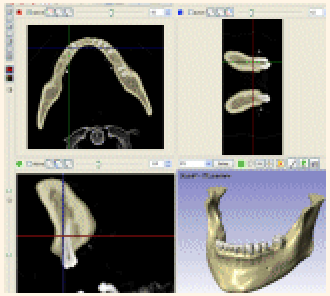
CAD & FE/CFD model

COMSOL



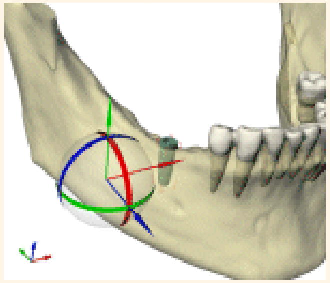
ScanIP

Image processing



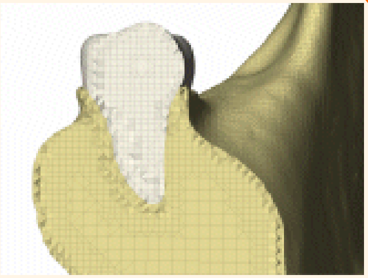
+ScanCAD

CAD import & positioning



+ScanFE

Volume mesh generation



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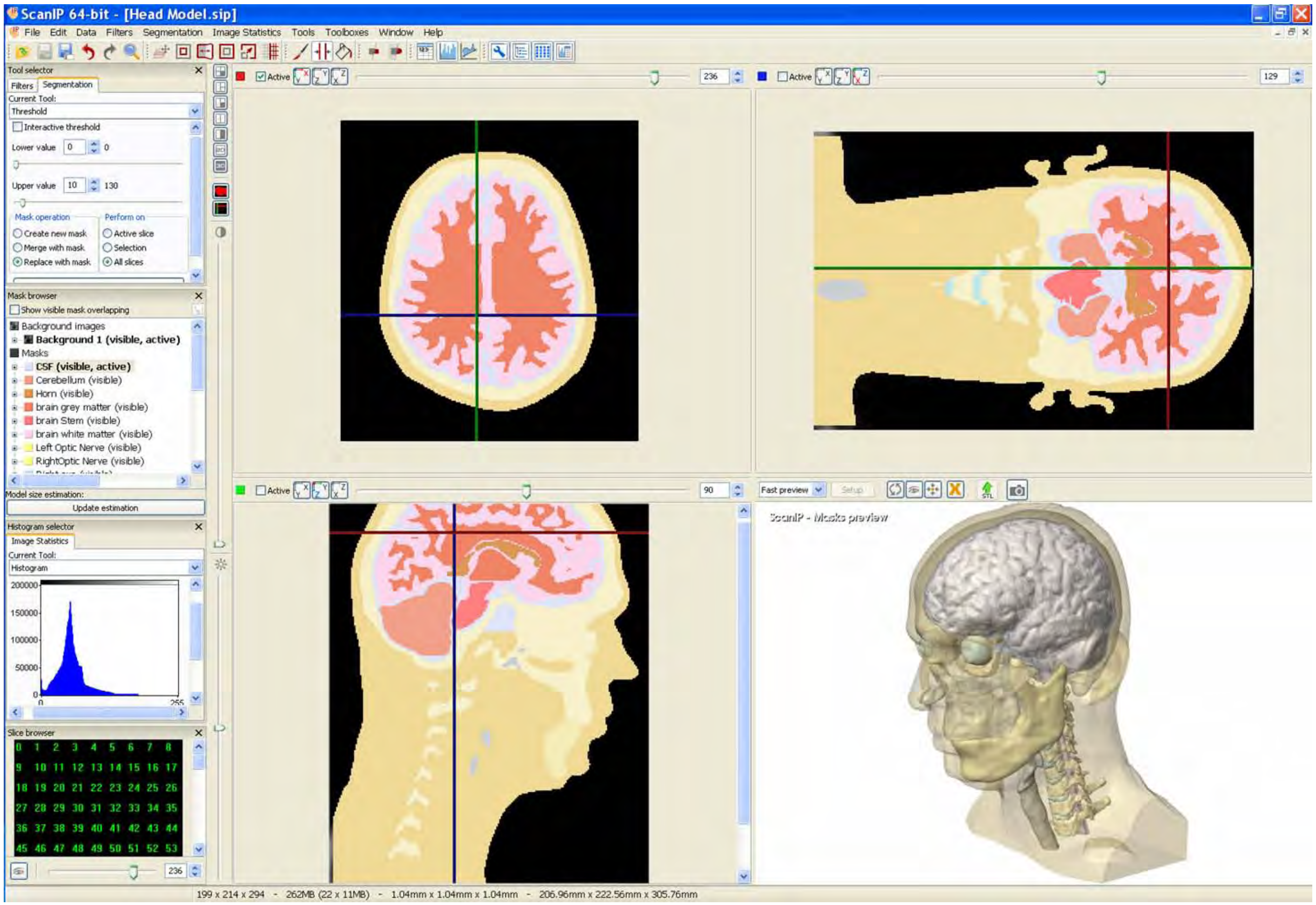
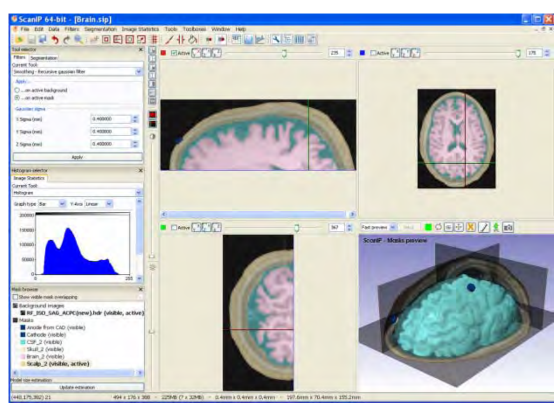
ScanIP software
Image Processing/Segmentation

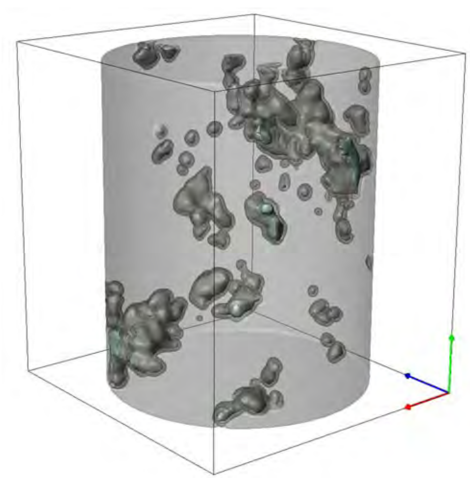


ScanIP

Complete image processing environment for importing, filtering, segmentation and CAD model generation.

- **Import** wide range of data formats: Dicom, stack of images…
- **Filters**: Noise reduction, smoothing, Metal Artifact Reduction…
- Manual and automated **segmentation** tools from paint to level set methods – threshold, floodfill etc.
- Multi-part anti-aliasing, smoothing and surface reconstruction
- **Export** surfaces directly to ANSYS, Abaqus, STL for meshing





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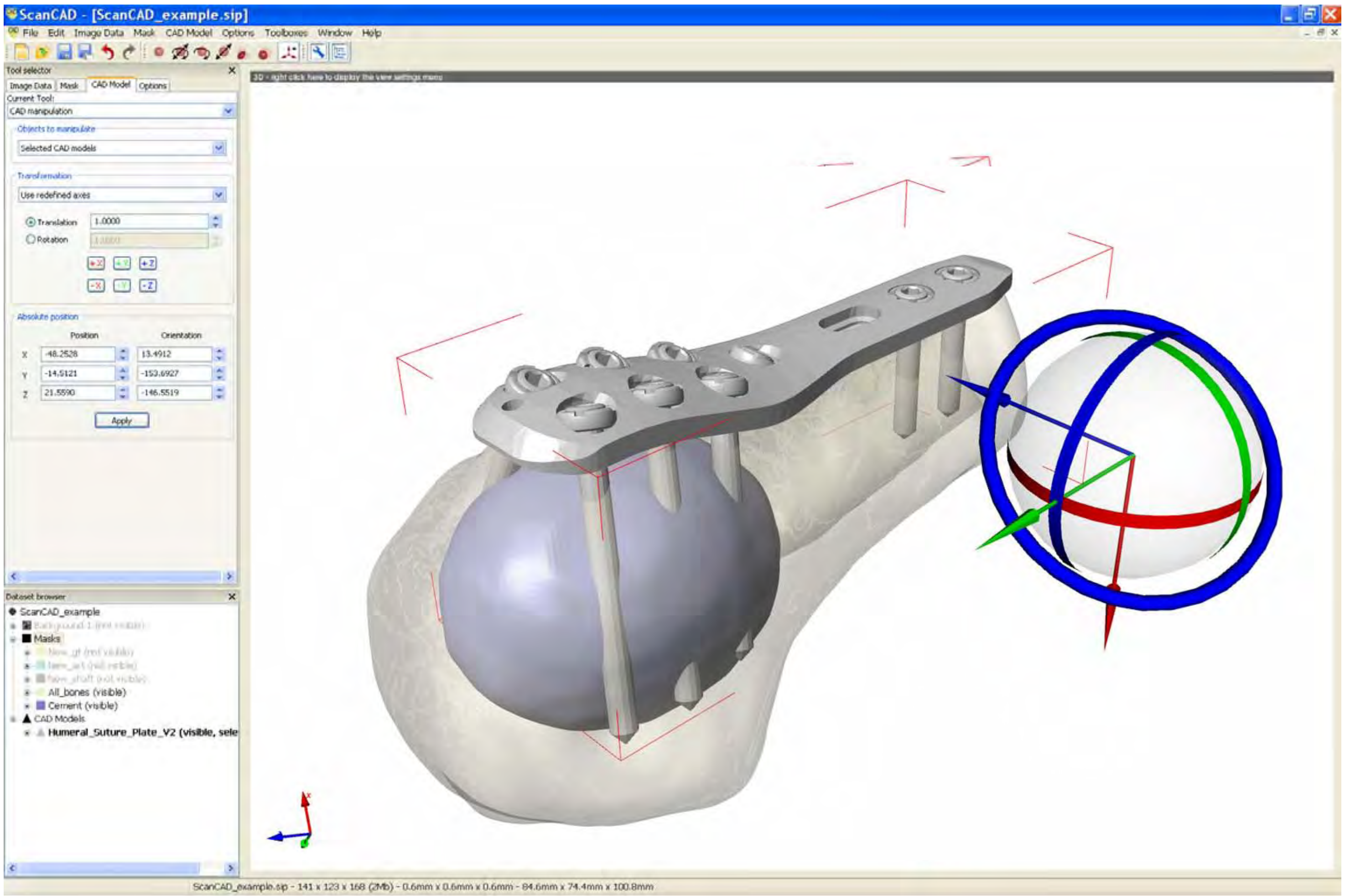
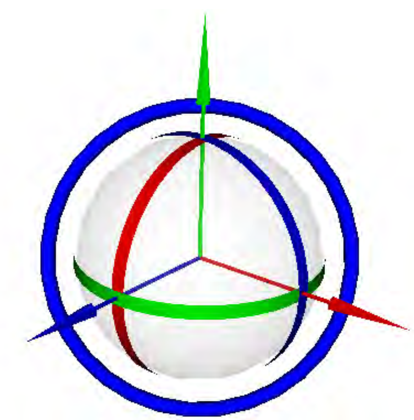
+ScanCAD module
Import and positioning of CAD data

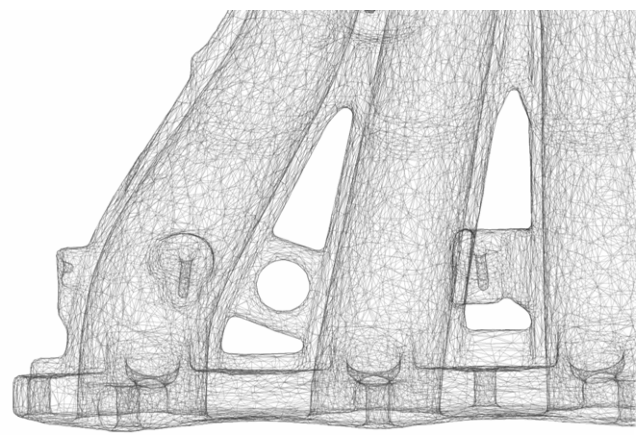


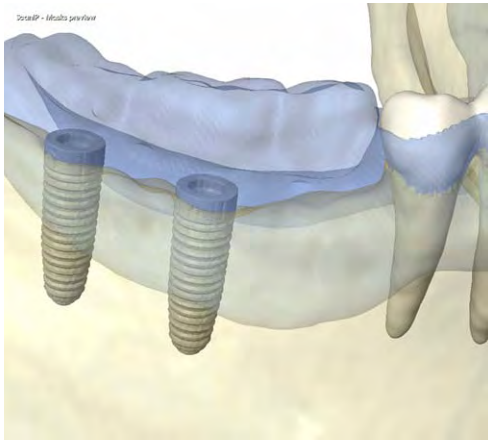
$^{+}$ScanCAD

Bolt on module for integration of CAD datasets.

- Direct **import** of most common CAD formats and support of multiple CAD imports (*.stl, *.stp and *.igs)
- Intuitive interactive **3D positioning** widget
- Export of multi-part STL and CAD (e.g. bone – implant)
- **Automated** meshing for FE/CFD analysis







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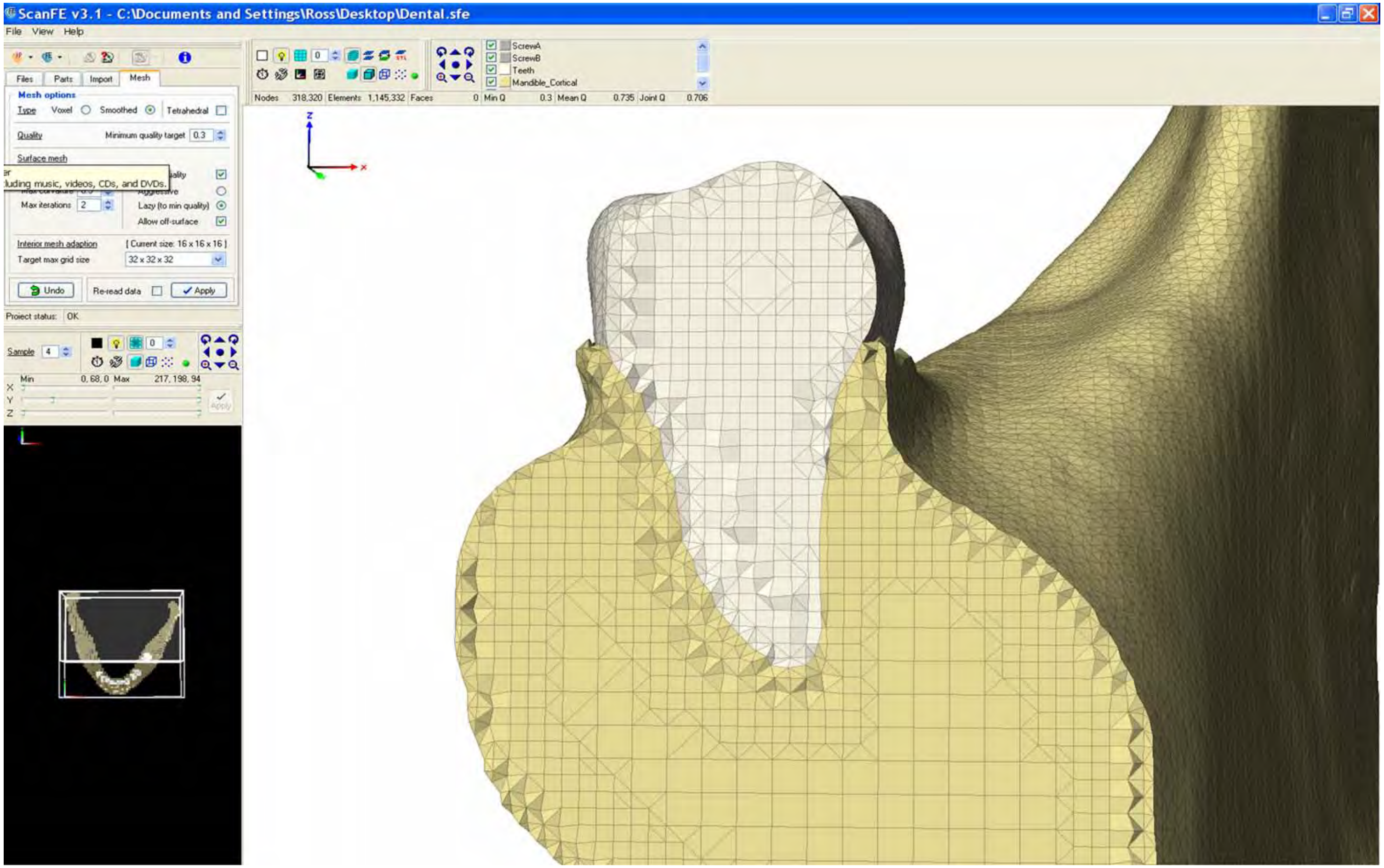
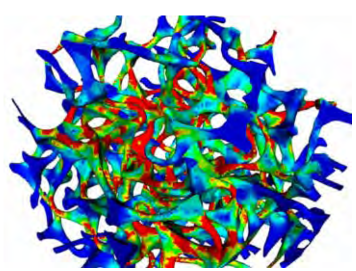
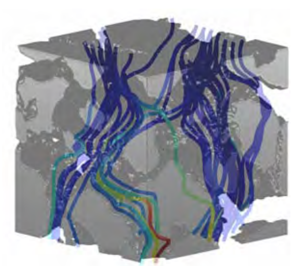
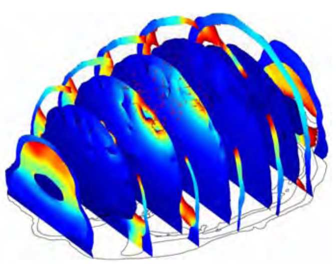
+ScanFE module
FE/CFD mesh generation



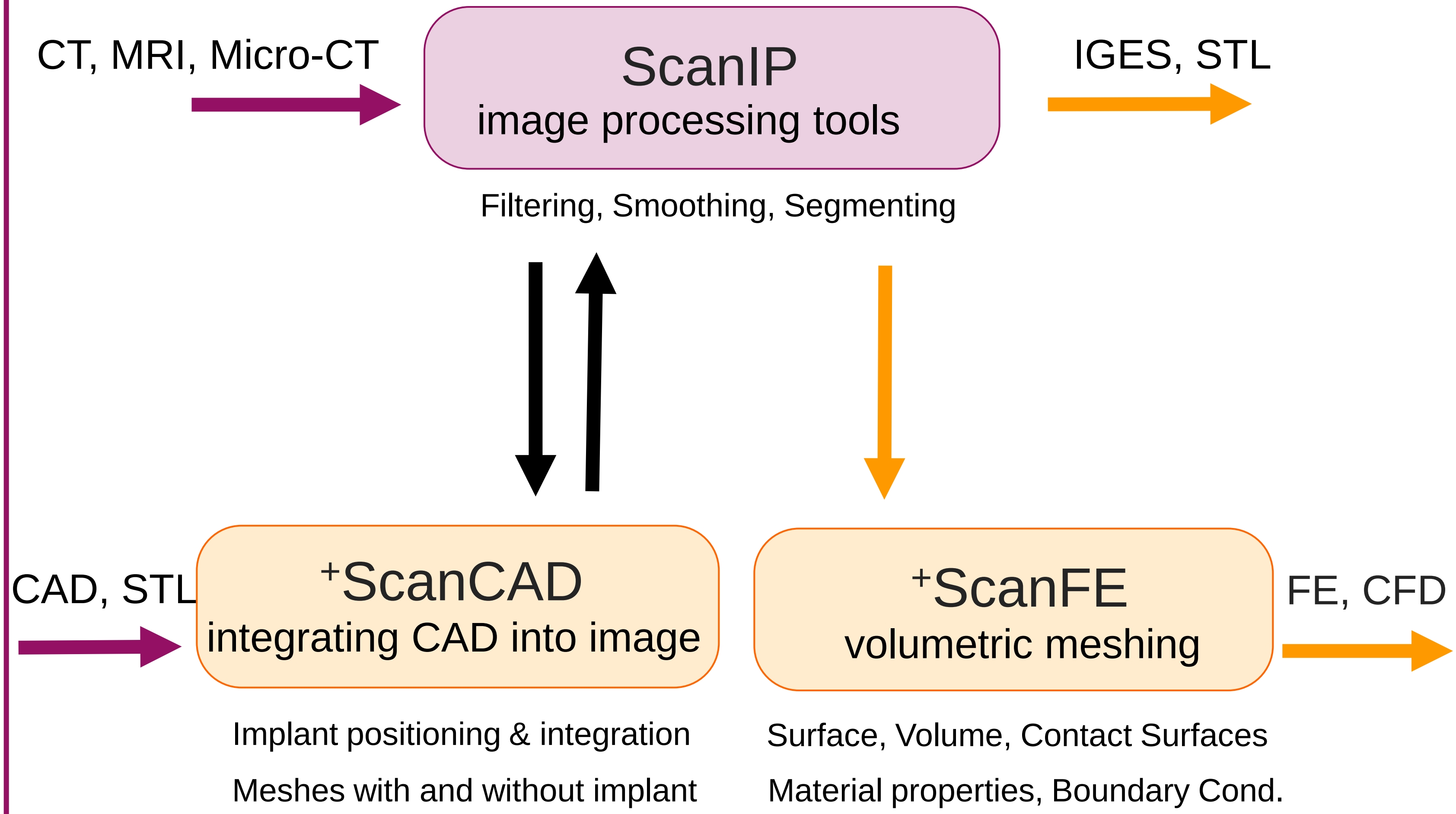
$^{+}$ScanFE

Bolt on module, proprietary volume and surface mesher.

- **Multipart** volume meshing (up to 250 parts)
- FE/FV: Generation of models for **multi-physics** simulations
- Surface/shell element generation
- **Contact** definitions
- **Material properties** assignation based on signal strength
- **Exports** directly to:
  Abaqus, Ansys, Ls-Dyna, Comsol, I-Deas, Patran, Fluent

Simpleware - Software Integration



Case Study

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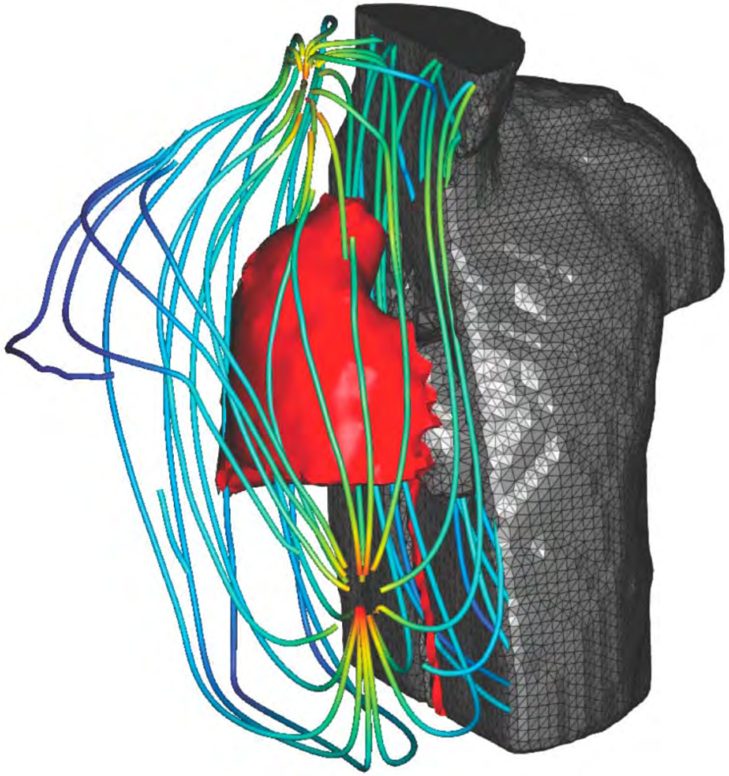
Human thorax for cardio-pulmonary applications

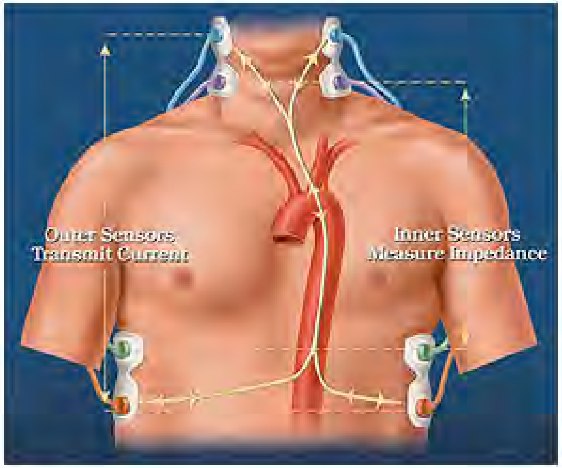


Introduction

- 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
  - Impedance Cardiography (ICG)
  - Electric Impedance Tomography (EIT)
- This study focuses on calculating the current distributions for ICG and EIT in models of the human thorax.

Method

How ICG Works:

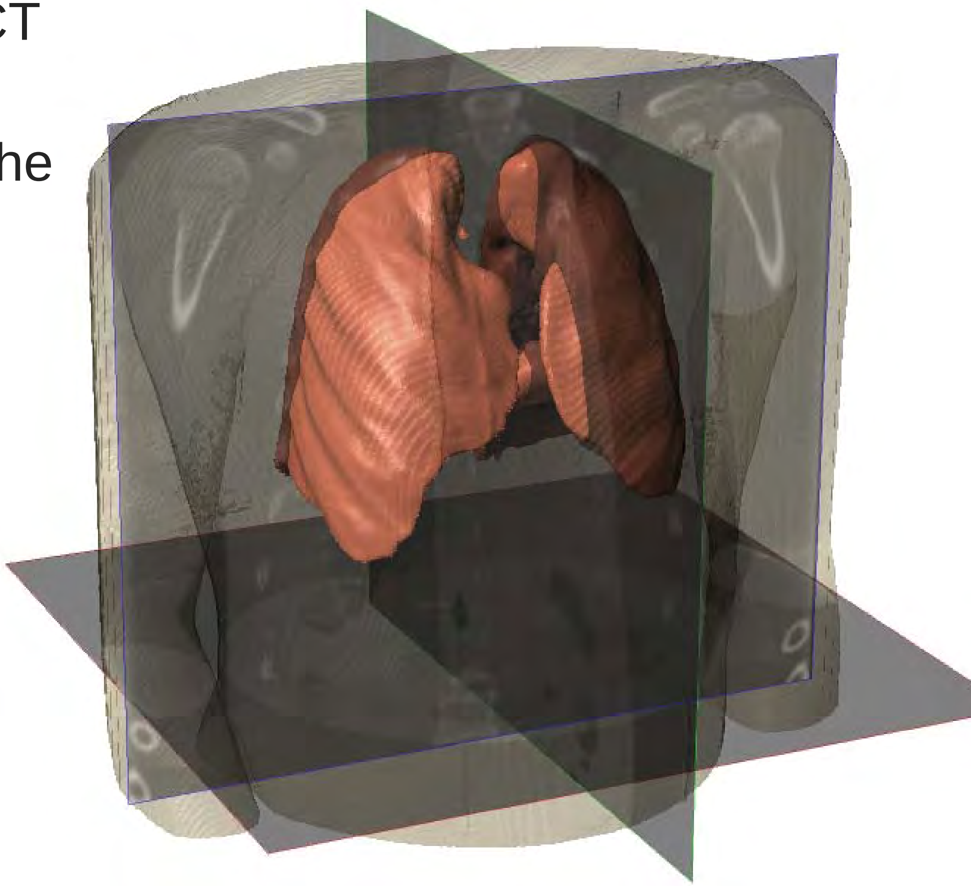


- An alternating current is transmitted through the chest.
- The current seeks the path of least resistance: the blood filled aorta.
- Baseline impedance to current is measured.
- Blood volume and velocity in aorta change with each heartbeat.
- Corresponding changes in impedance are used with ECG to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

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



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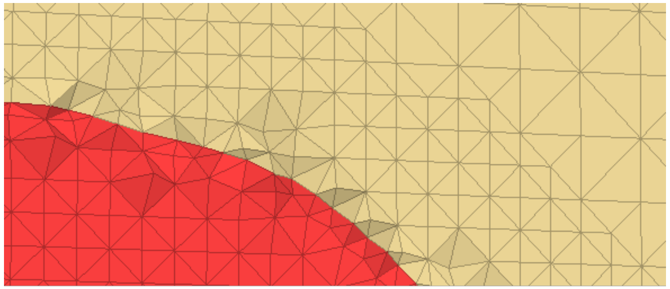
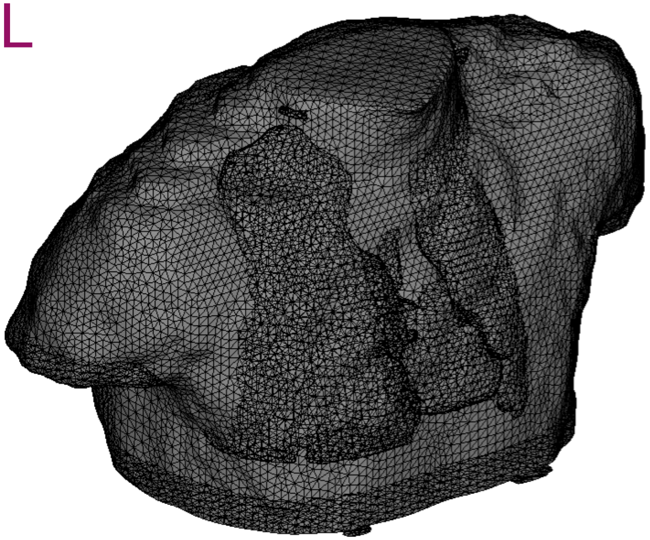
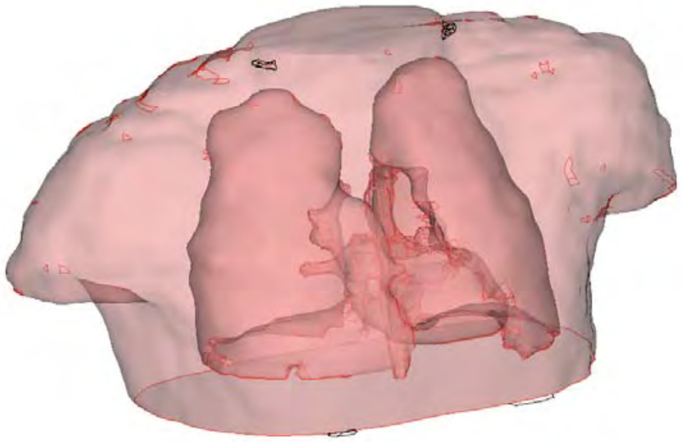


Exported FE Mesh in COMSOL

- 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.



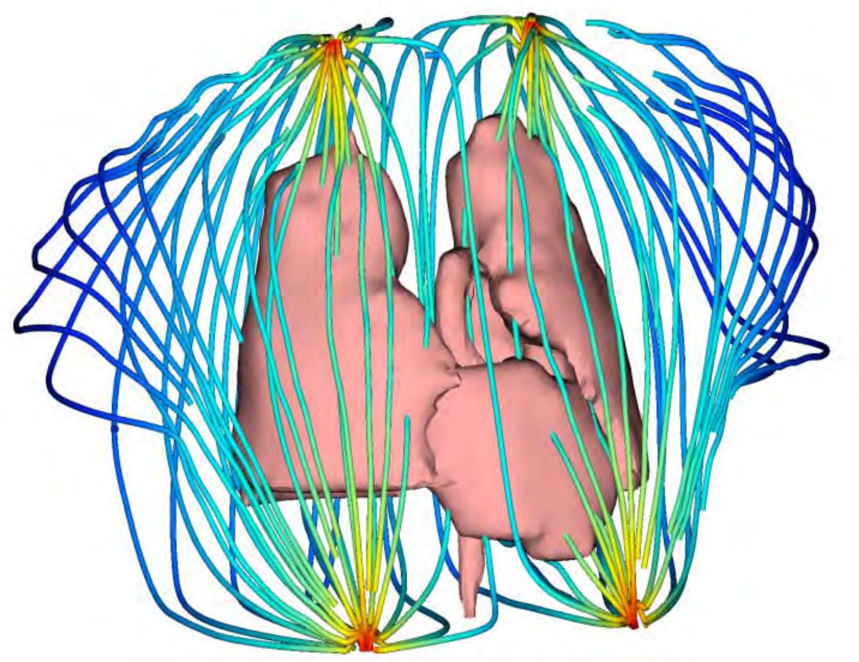
The FEM mesh



Subdomain settings: electrical resistivities

Results

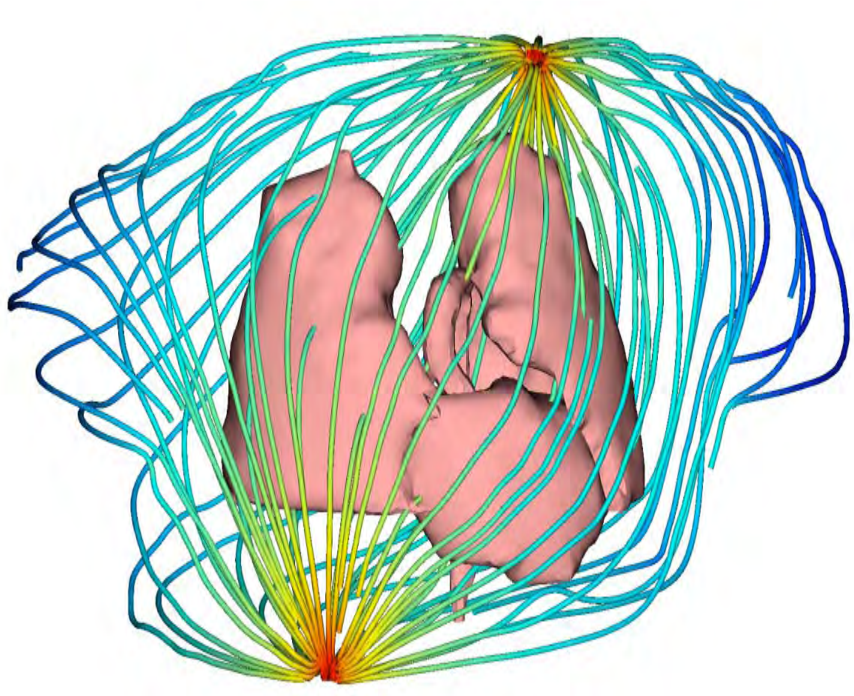
- FEM solution of the four current electrode setup



  - 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

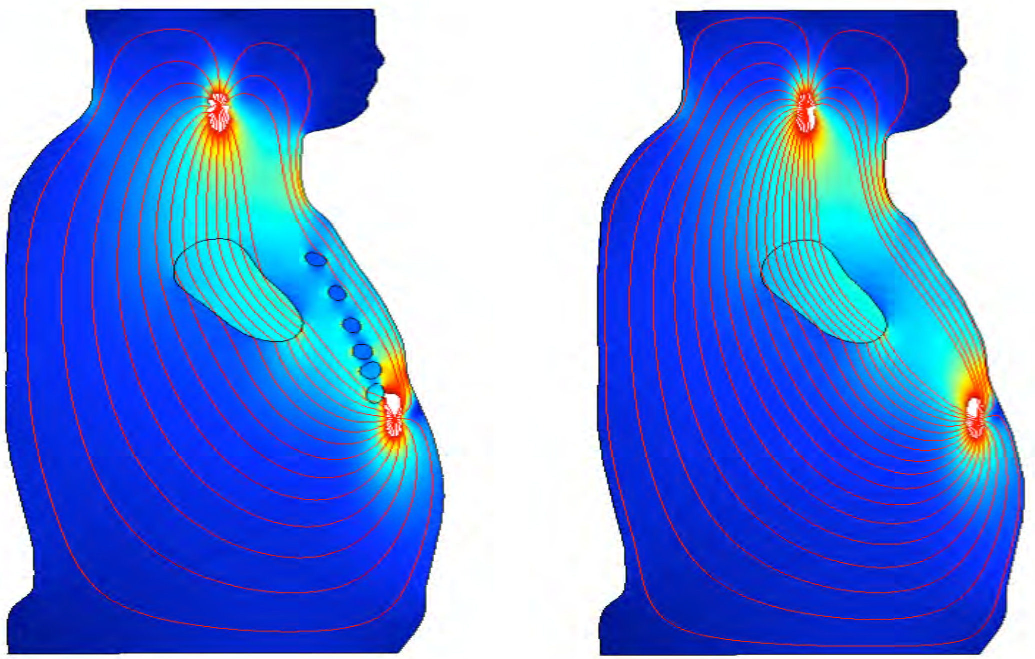
- FEM solution of the two current electrode setup



  - Electrical current streamlines are quite widely distributed through the thorax

Results

- Effect of modelling bone structure



  - 2D finite element simulations of an ICG experiment in the sagittal plane.
  - When ribs are taken into account the electrical current percentage through the heart is 6,91%. Without ribs the model gives a value of 6.86%.

Influence of breathing and cardiac cycle

	end-diastolic		end-systolic	
	expiratory	inspiratory	expiratory	inspiratory
tissue	%	%	%	%
muscle	85,6%	82,0%	83,6%	80,6%
left lung	3,8%	5,6%	4,5%	6,8%
right lung	4,4%	6,5%	5,5%	7,5%
total lungs	*8,2%*	*12,1%*	*10,0%*	*14,3%*
heart	5,5%	5,2%	5,5%	4,3%
aorta	0,7%	0,7%	0,9%	0,8%
total	100,0%	100,0%	100,0%	100,0%

Results of four electrode ICG FEM model, percentage of organs current volume integral to total current volume integral

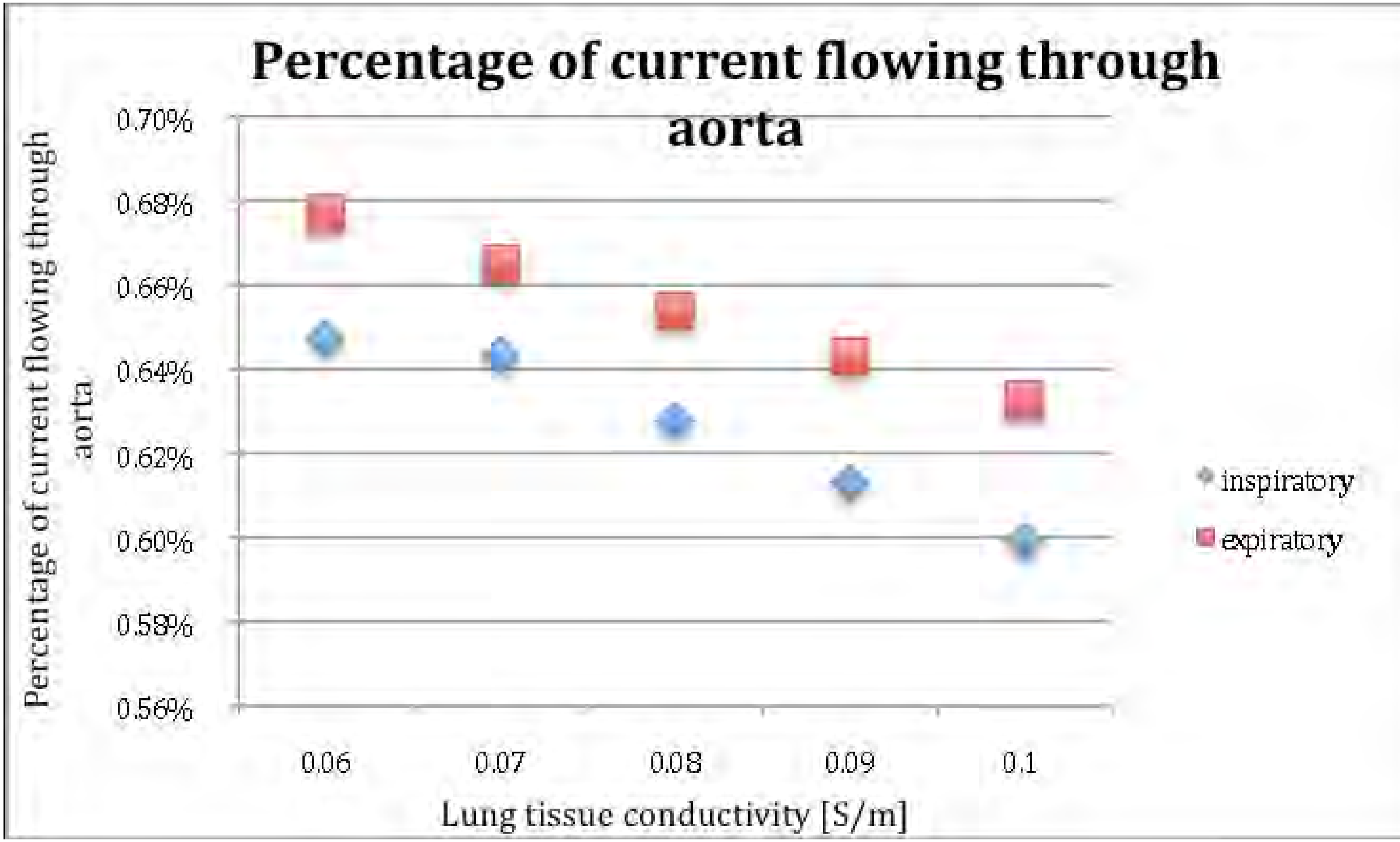
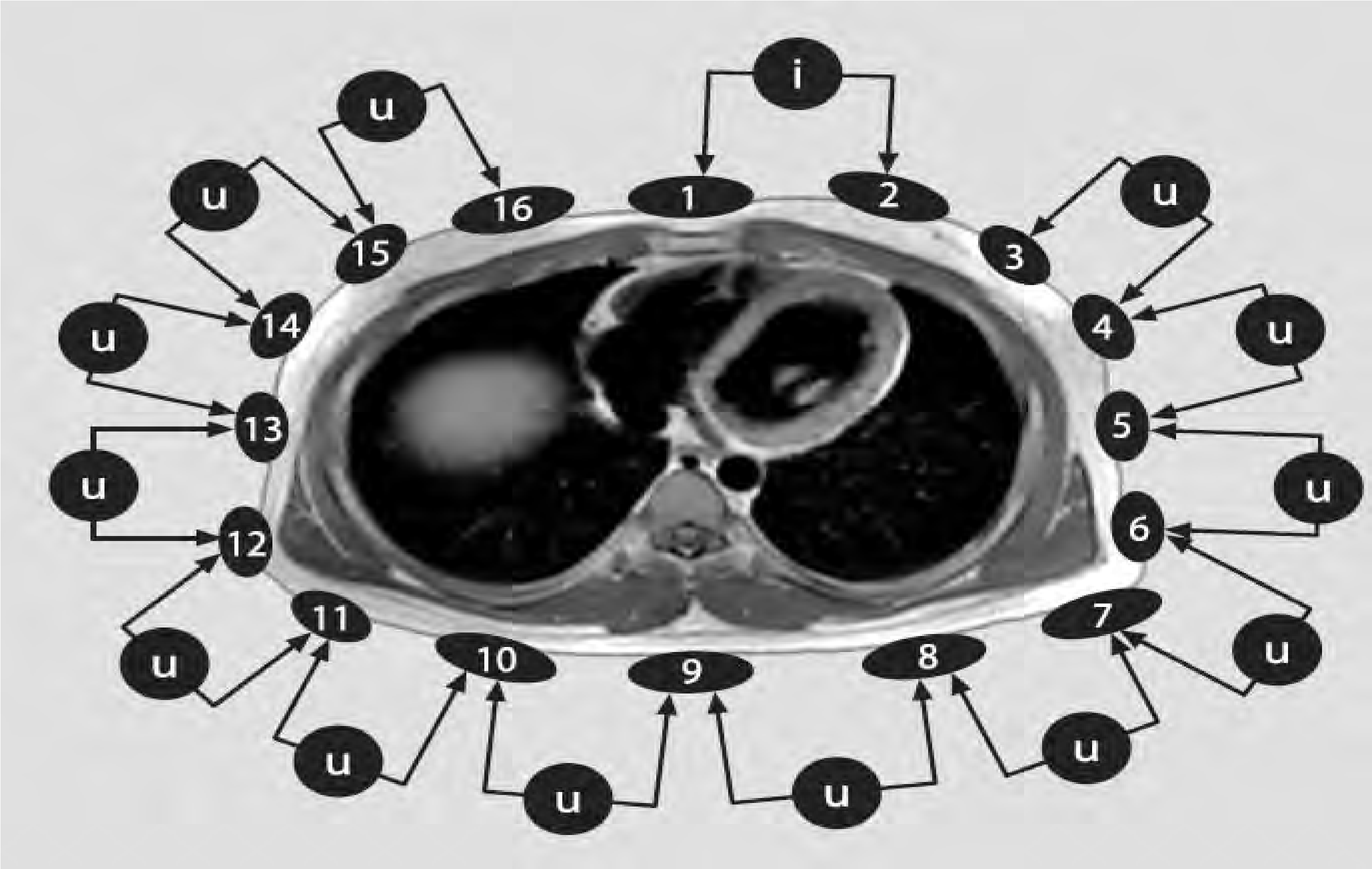


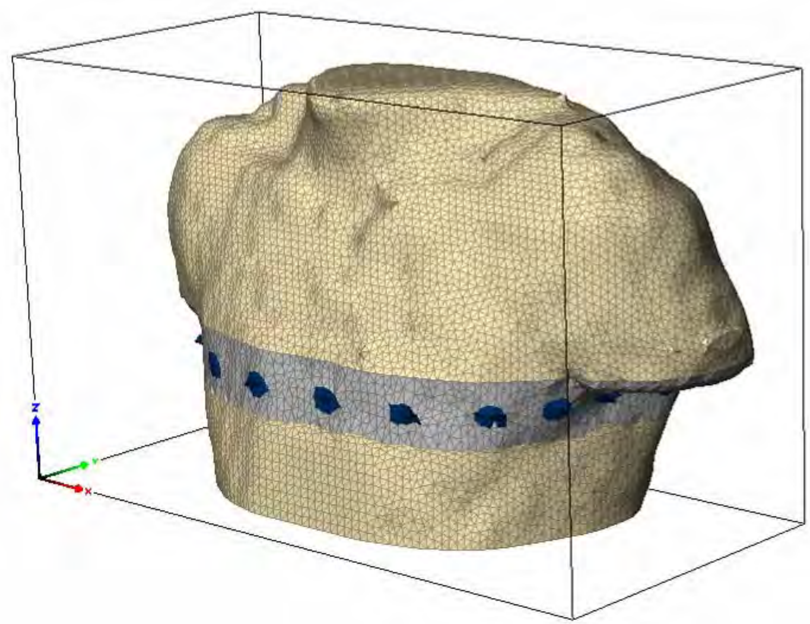
Figure 42 Percentage of current through lungs, expiratory and inspiratory state,with different lung tissue conductivities, VUmc MRI dataset

FE for Electrical Impedance tomography



Simpleware generated Finite Element Model for IET

- ScanIP the 16 electrodes are drawn around the thorax in the segmentation process.
- ScanFE then created the FEM mesh
- Comsol the geometry is imported.
- 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

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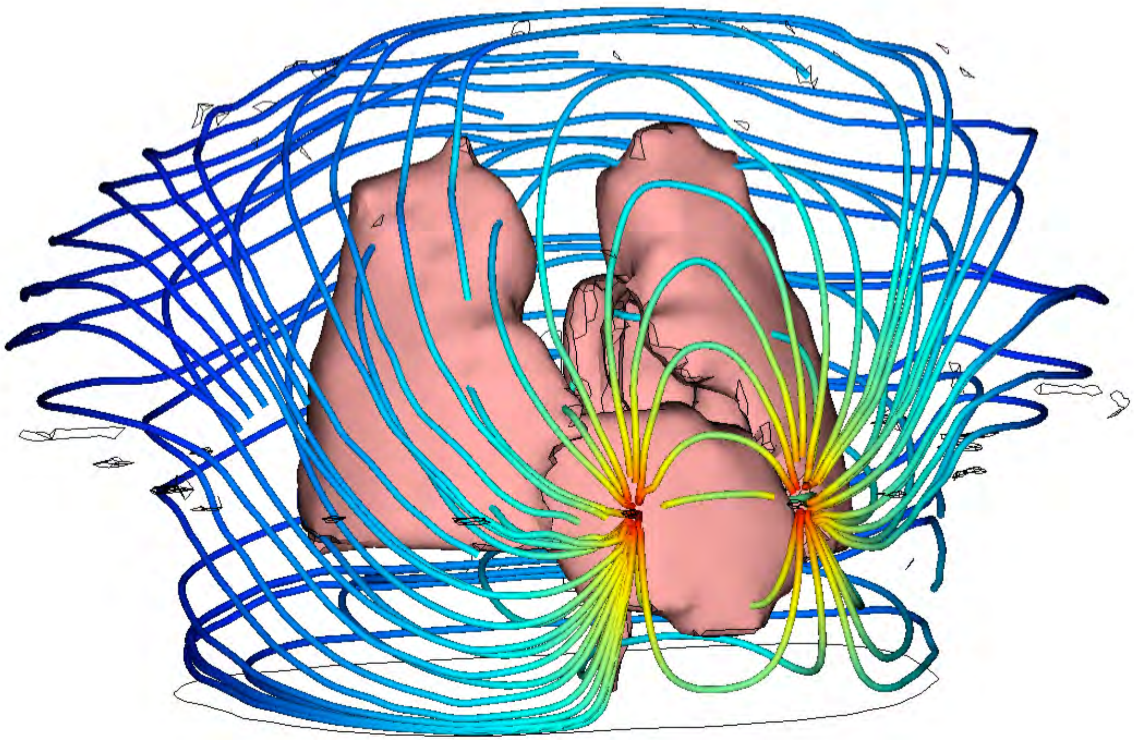
Results

- Influence of Breathing and Cardiac Cycle



Electrical current distribution through upper thorax organs in a FEM modelled EIT experiment

Tissue	**Expiratory**	**Inspiratory**
Muscle	84,3%	82,2%
heart	3,4%	2,9%
aorta	0,7%	0,7%
left lung	3,6%	4,5%
right lung	7,9%	9,7%
Total	**100,0%**	**100,0%**
total lungs	**11,5%**	**14,2%**

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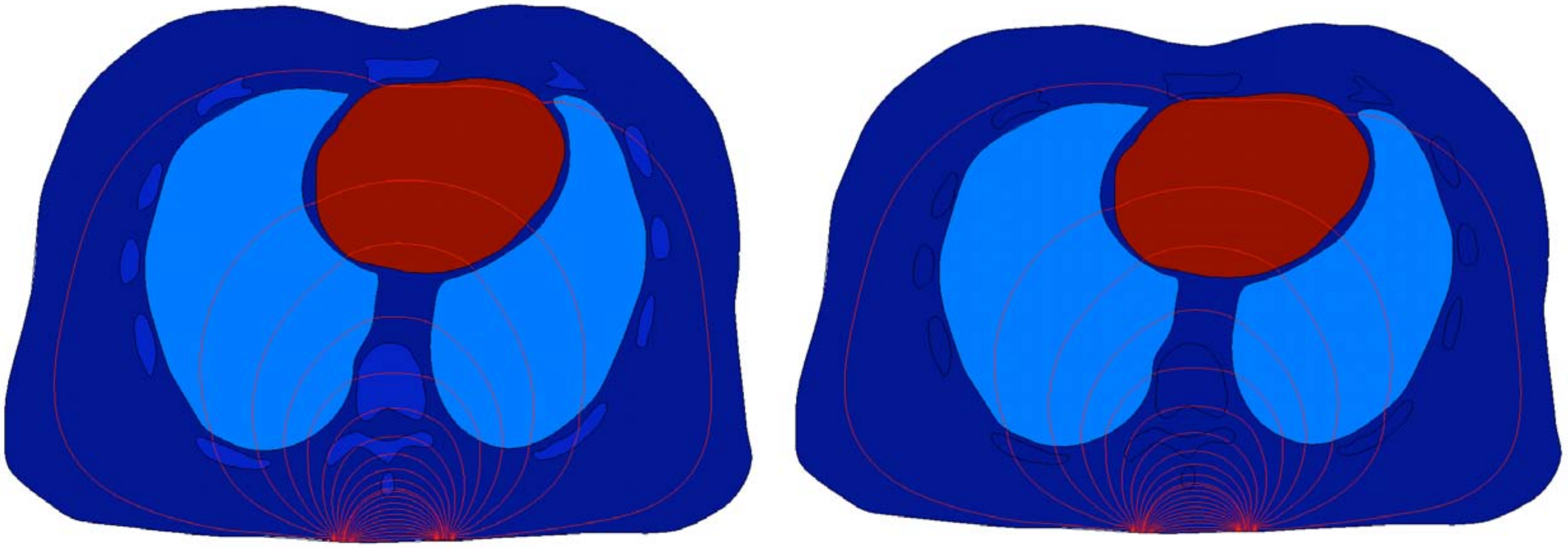
Electrical current distribution divided by conductivity through upper thorax organs in a FEM modelled EIT experiment

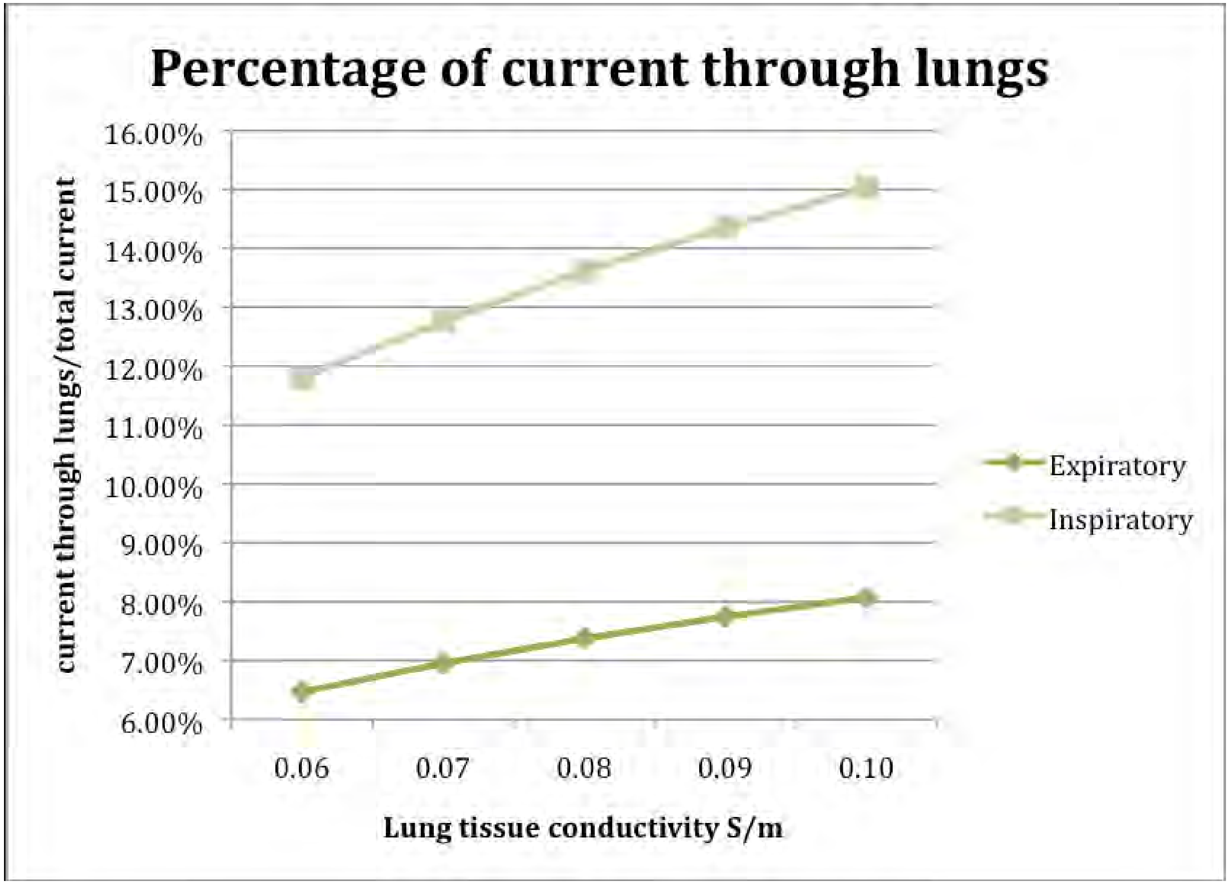
Tissue	Expiratory	Inspiratory
muscle	72,3%	68,2%
heart	2,7%	2,2%
Aorta	0,2%	0,2%
left lung	7,8%	9,4%
right lung	16,9%	20,0%
Total	**100,0%**	**100,0%**
total lungs	**24,8%**	**29,4%**

2D finite element model of applying EIT on the human thorax, with and without bone structure



In the model with bone structure, the current percentage through the lungs is 23,0%. The right picture, where the bone structure is not taken account, this percentage is 23,3.

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

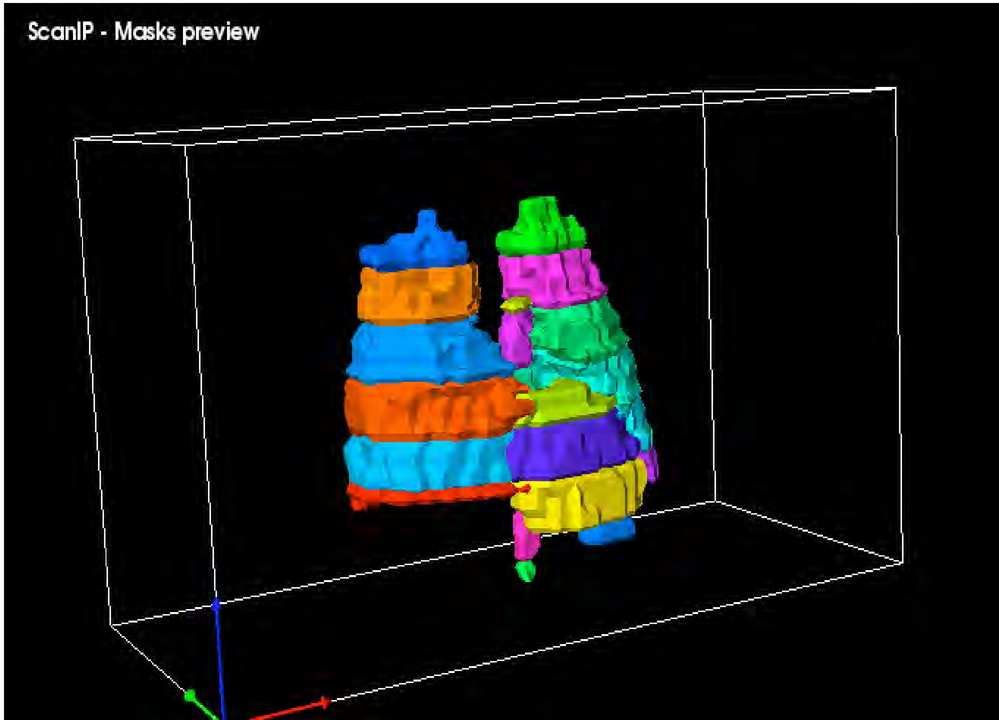


Out-of-plane current

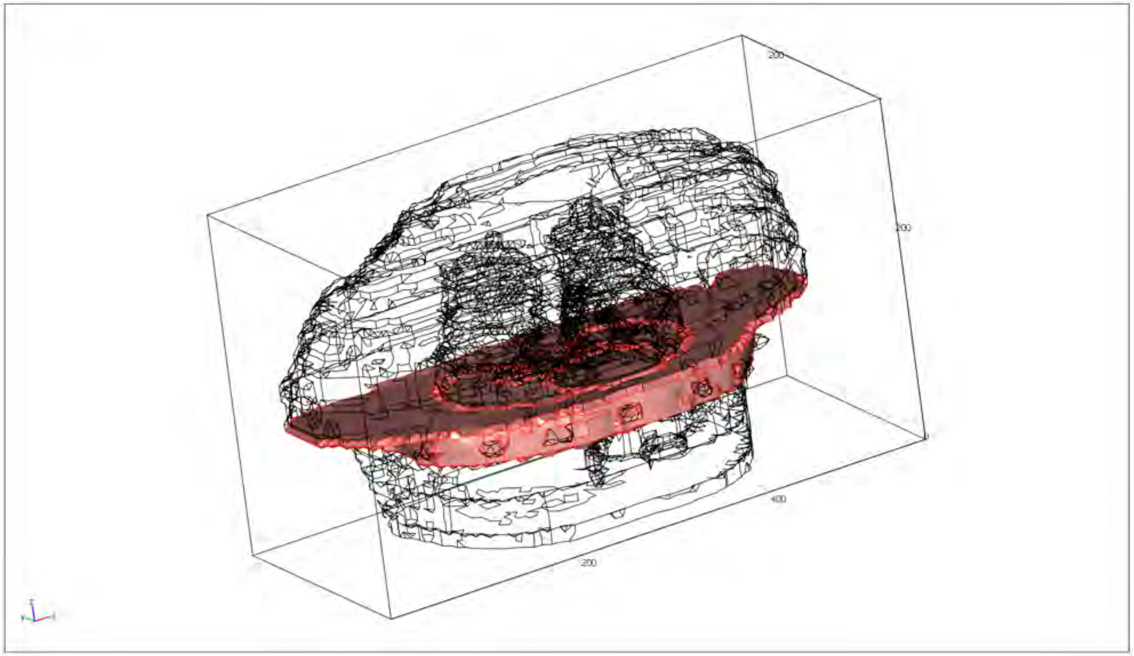
❑ The geometry was split up in slices above and below the electrode plane, each with a thickness of 6,4 cm.

❑ This thickness corresponds with a stack of 5 MRI images.

❑ ScanIP offers boolean operations to act on segments so that the original geometry is not altered.



Comsol the layers appear as different subdomains



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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