TECHNISCHE UNIVERSITÄT ILMENAU

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Institut für Biomedizinische Technik und Informatik

Electromagnetic inverse problems in biomedical engineering

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Presentation at the Politecnico di Milano on March 14, 2008

Overview

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1. Introduction
2. Localization of magnetic markers in the alimentary tract
3. The influence of forward model conductivities on EEG/MEG source reconstruction
4. Optimization of magnetic sensor arrays for magnetocardiography
5. Validation of source reconstruction procedures

Magnetocardiography (MCG)

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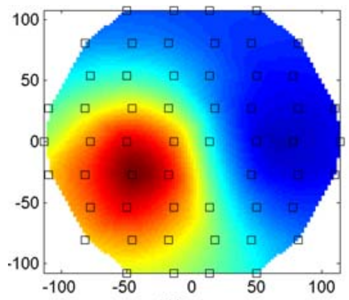
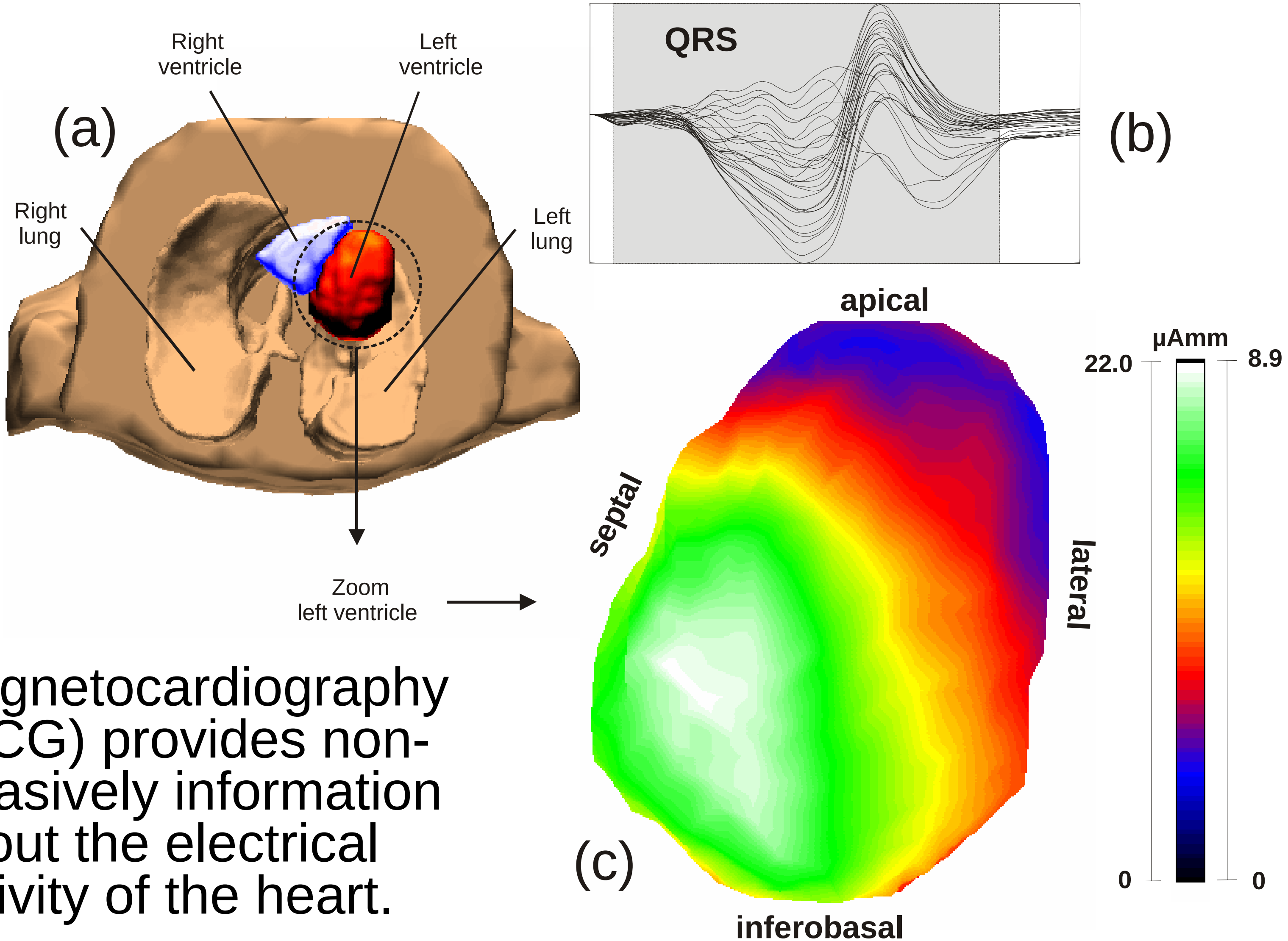
- Measurement of magnetic field produced by the heart
- Reconstruction of electric sources causing the field



MCG



Magnetocardiography (MCG) provides non-invasively information about the electrical activity of the heart.

Introduction

- New room temperature optical magnetometers allow customized and flexible sensor arrangements
- Arising question: how do we arrange the sensors optimally?
- Goal function: condition number (CN) of the lead field (LF) matrix

BEM model

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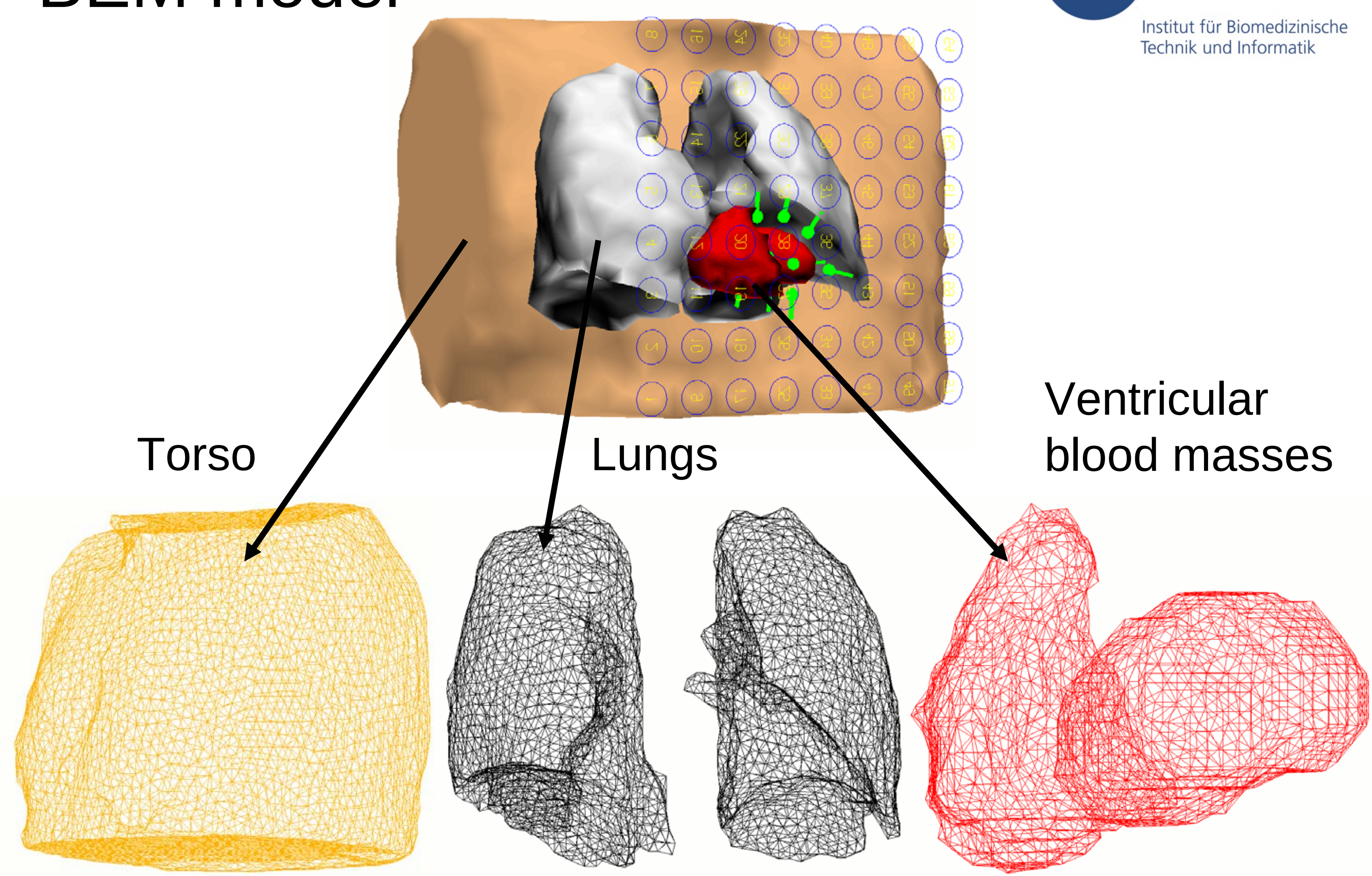

Source space

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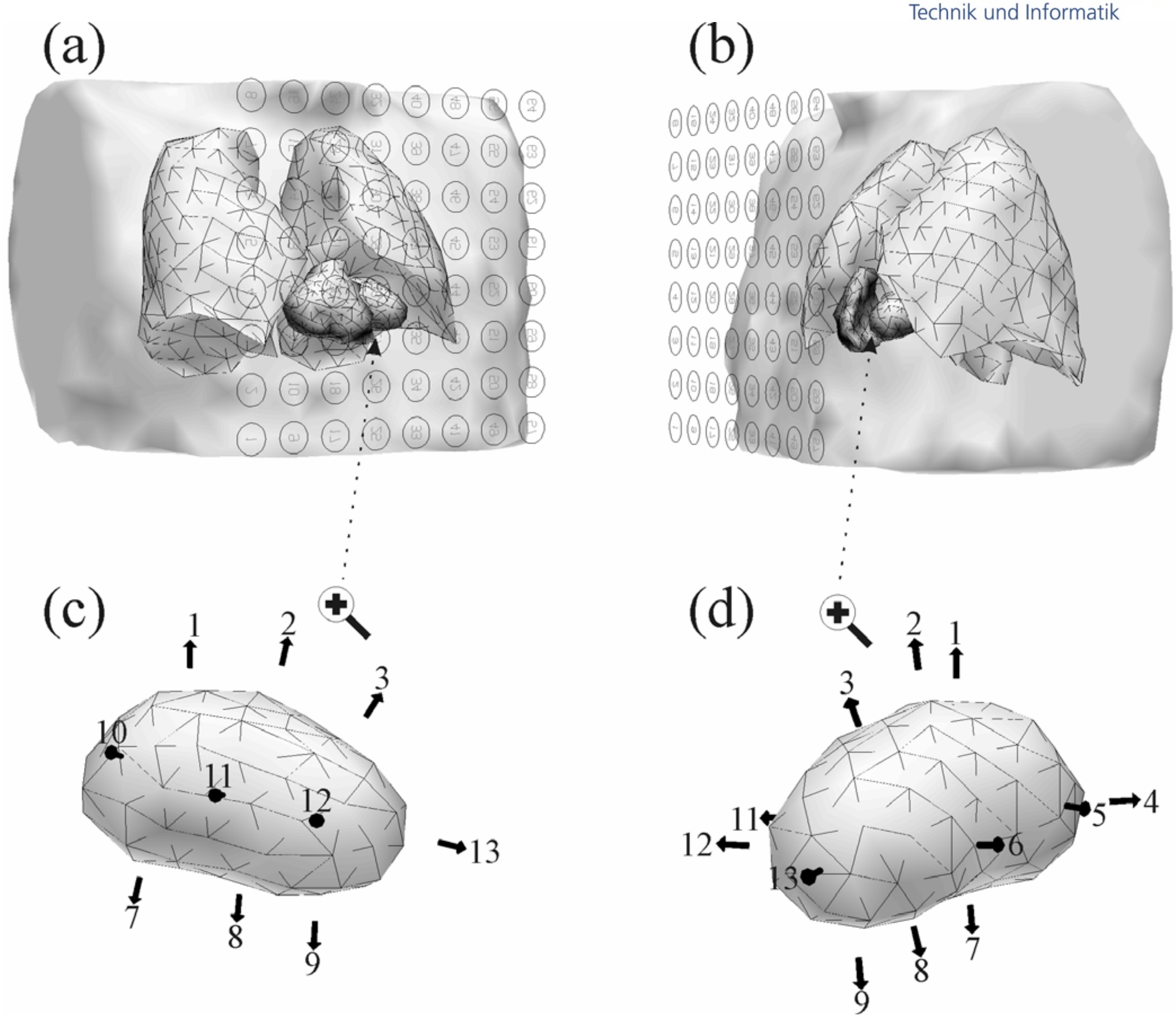
13 current dipoles, distributed around the left ventricle of the heart



The objective function

- LF matrix contains information on geometry of the source space, the boundary element model and the sensor array
- A minimal CN implies an optimal sensor arrangement for a given setup

Discretization of the search space

- Optimization: iterative search for a sensor setup with minimal CN
- But LF computation is slow, therefore pre-computation for a fixed grid of positions & orientations is needed

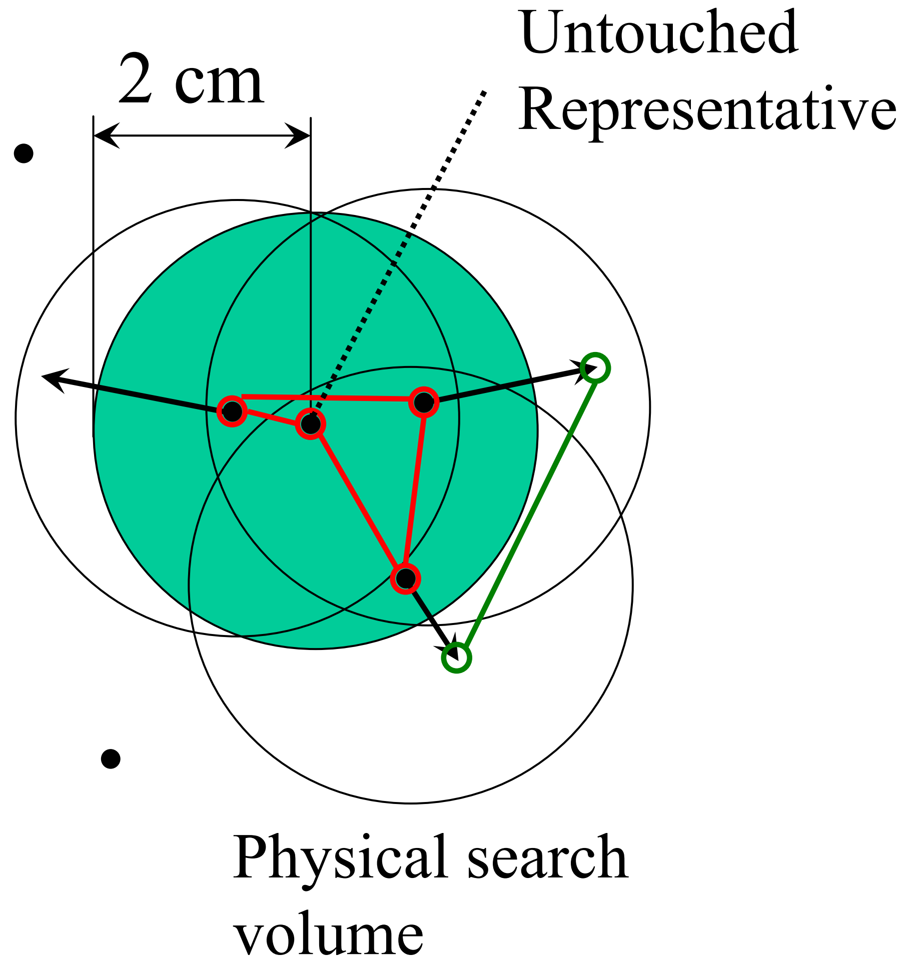
Constraint Framework for Continuous Optimizers

- Discrete search volume
  → snap into grid before each CN evaluation

- Minimum distance (MD) of sensors, here 2 cm
  → while mean(MD violation) > tolerance
  1. pick a sensor with max #clashes
  2. move all clashing sensors away radially
  3. snap into grid

- Pro: one representative sensor out of the clashing sensors is kept

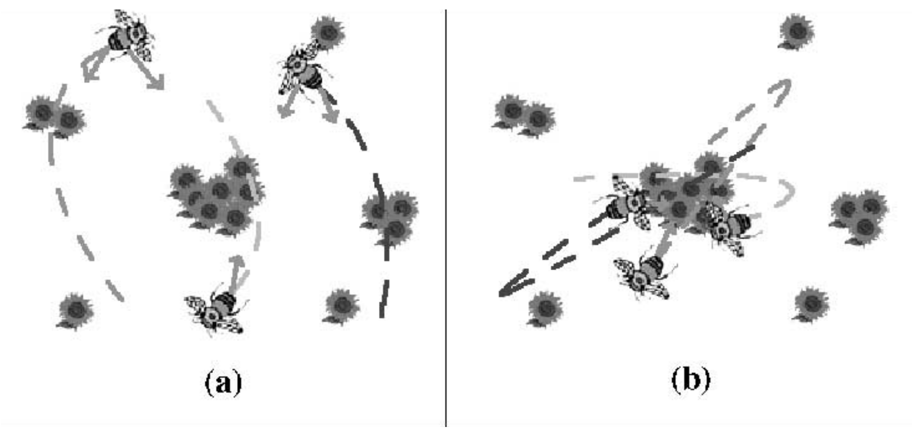
Restoring the minimum distance

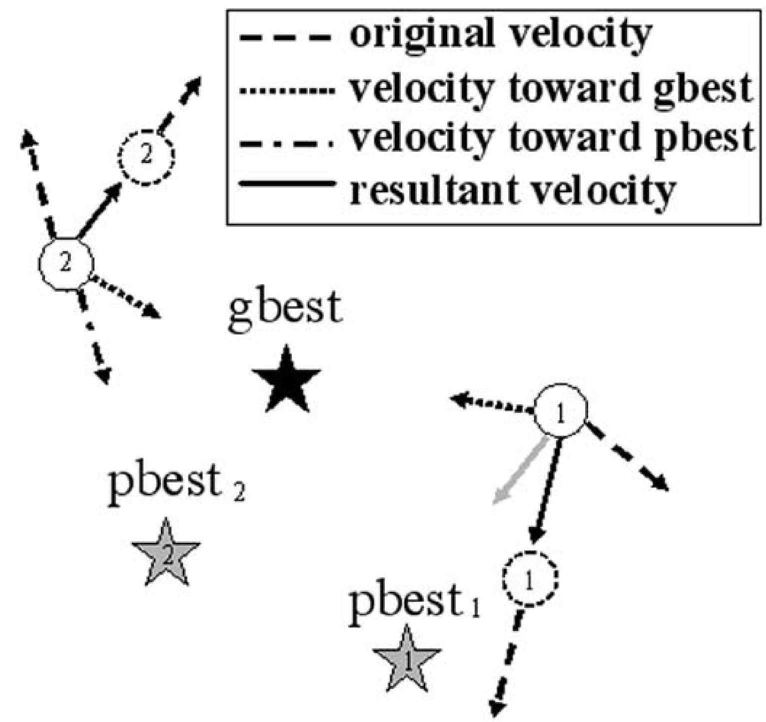


Particle Swarm Optimization (PSO)

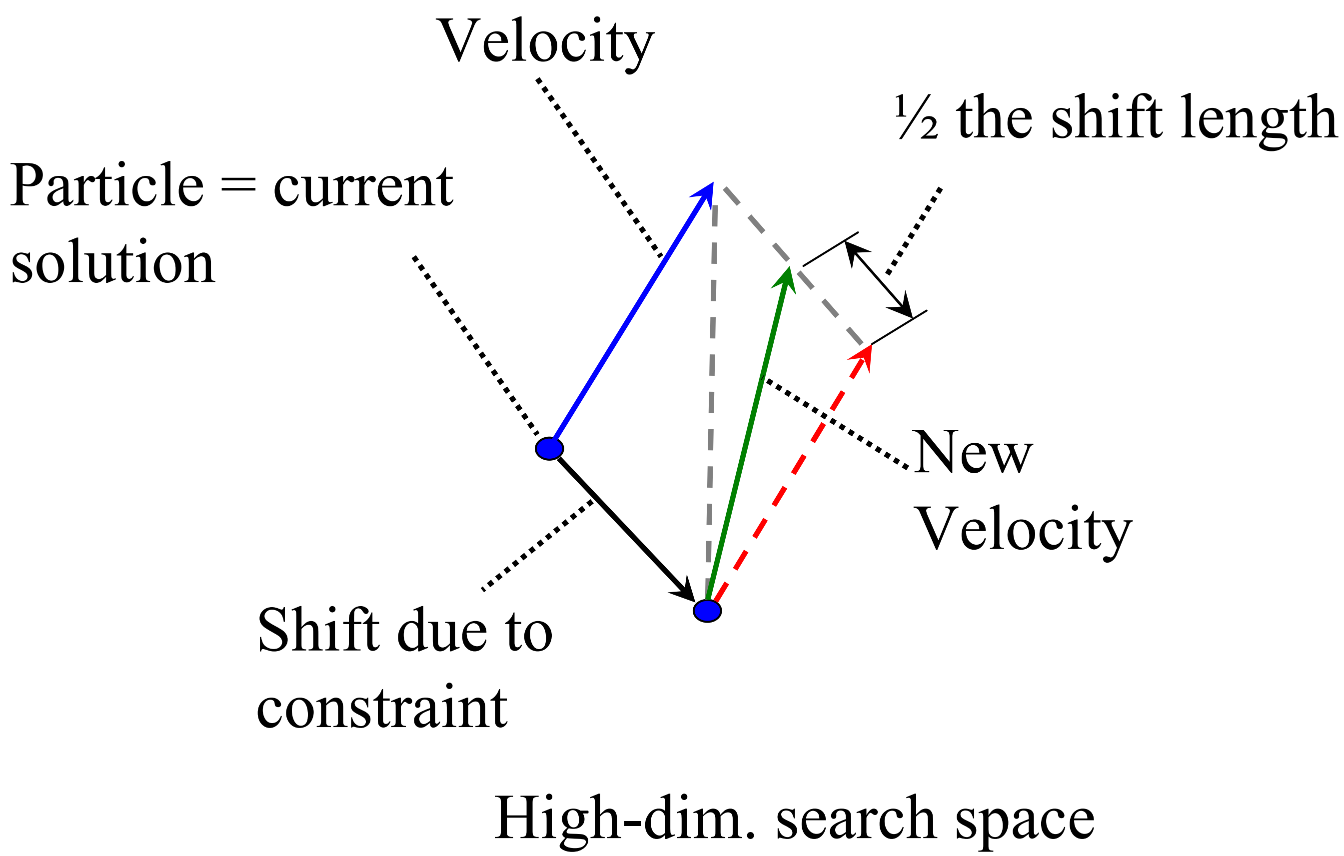
- A set of candidate solutions (= particles) is randomly initialized
- Each particle has a position and velocity in high-dim. search space
- Each particle has informant particles, whose state it can access
- Iteration = move particles + update velocities + fix constraint
- After constraint fix, the velocities are corrected

PSO algorithm





PSO velocity correction



Tabu Search (TS)

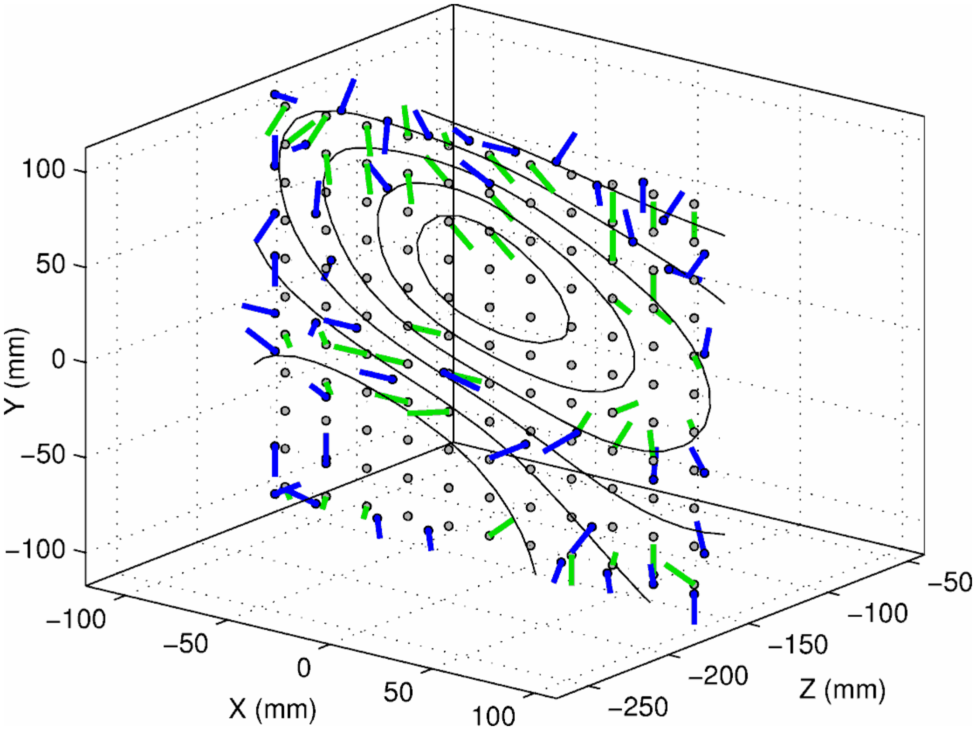
- Discrete search: combinatorial selection of *s* out of *r* sensors with minimal CN
- The minimum distance constraint is satisfied for all sensor selections
- In each iteration step: find a better selection of *s* sensors (with lower CN) in the neighborhood of the current solution by exchanging *n* sensors (during the search *n* was decreased from *s*/2 to1)

PSO vs. TS

- TS prevents reevaluations of sensor configurations by memorizing them
- TS is robust against local minima
- But: no use of spatial closeness or gradient, limited to combinations of predefined sensor positions/orientations
- Dense grids (i.e. a higher number of sensors on the same area) may be more difficult to optimize than sparse ones because of the combinatorial complexity

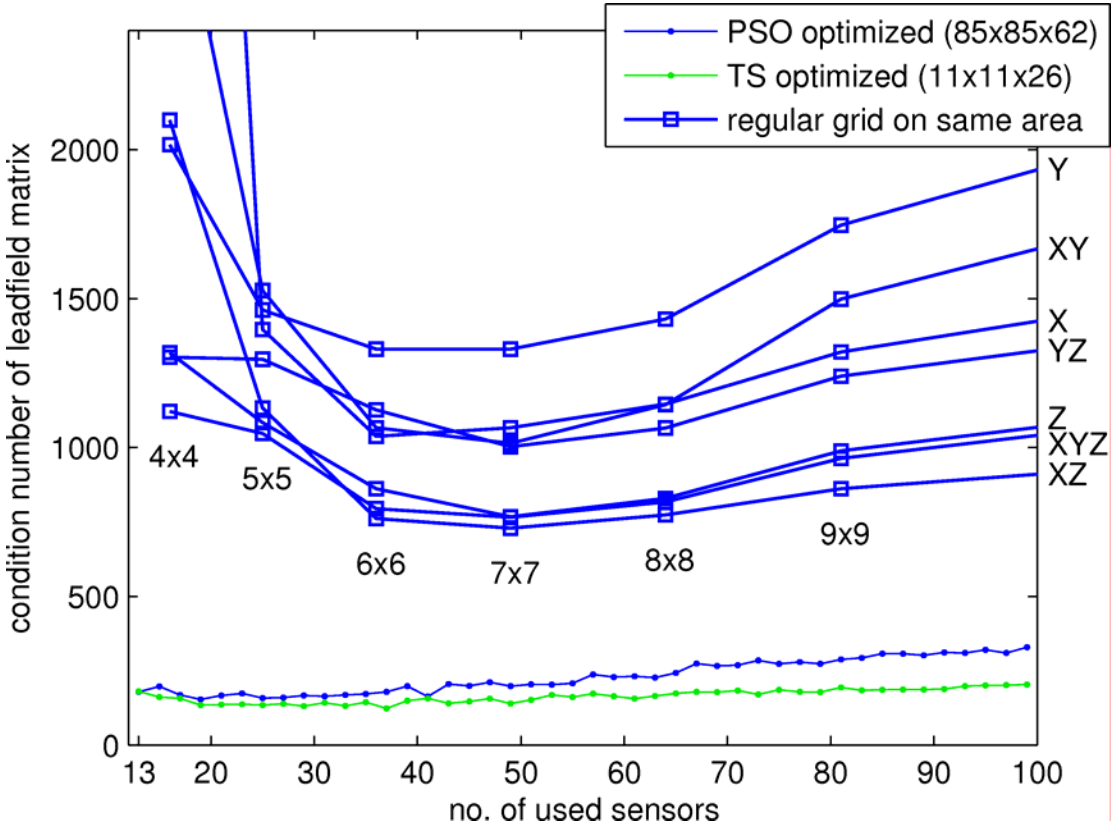
Numerical Results

- PSO and TS are implemented in C++ in SimBio: TS (green) and PSO (blue) optimized setups are very similar



Reduction of CN

- Both optimizations significantly reduce CN



Conclusion

- Comparable results indicate that optimization of vectorial sensor setups may be significantly improved
- Reconstruction robustness may be improved and the number of sensors may be reduced while retaining information in terms of CN
- The new quasi-continuous PSO optimization incorporates the gradient and spatial closeness information while being robust against local minima in the goal function
- A fine 3D search volume, projection method based and lower error bound based sensor setup optimizations are planed

Lau, Eichardt, Di Rienzo, Haueisen: Tabu Search Optimization of Magnetic Sensor Systems for Magnetocardiography. IEEE Transactions on Magnetics, to appear 2008

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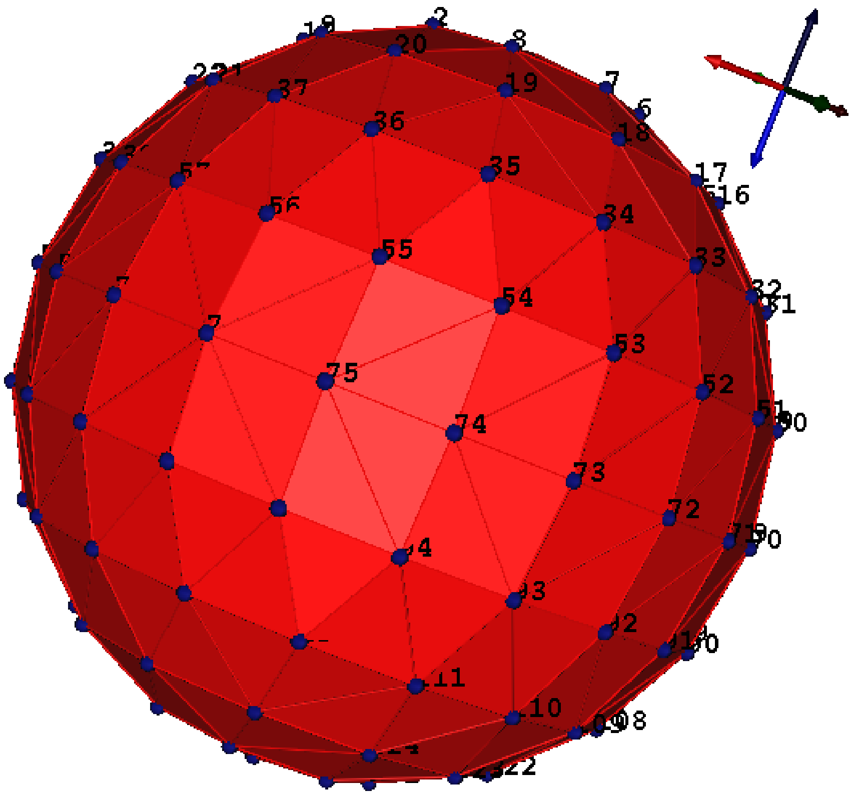
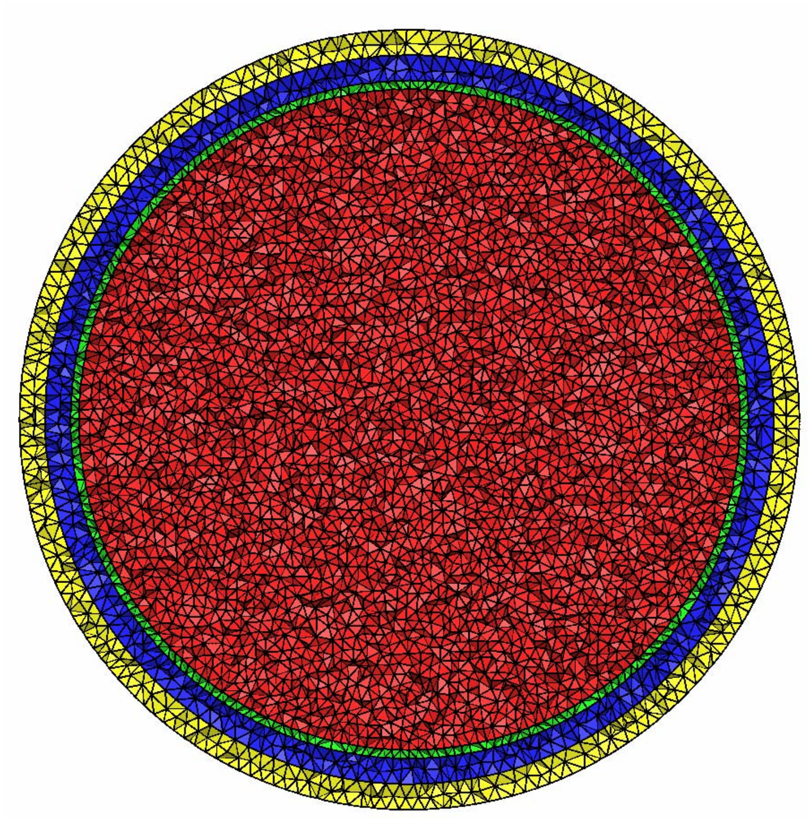
    1. Simulations
    2. Phantom measurements
    3. Animal measurements

Simulations





134 electrodes

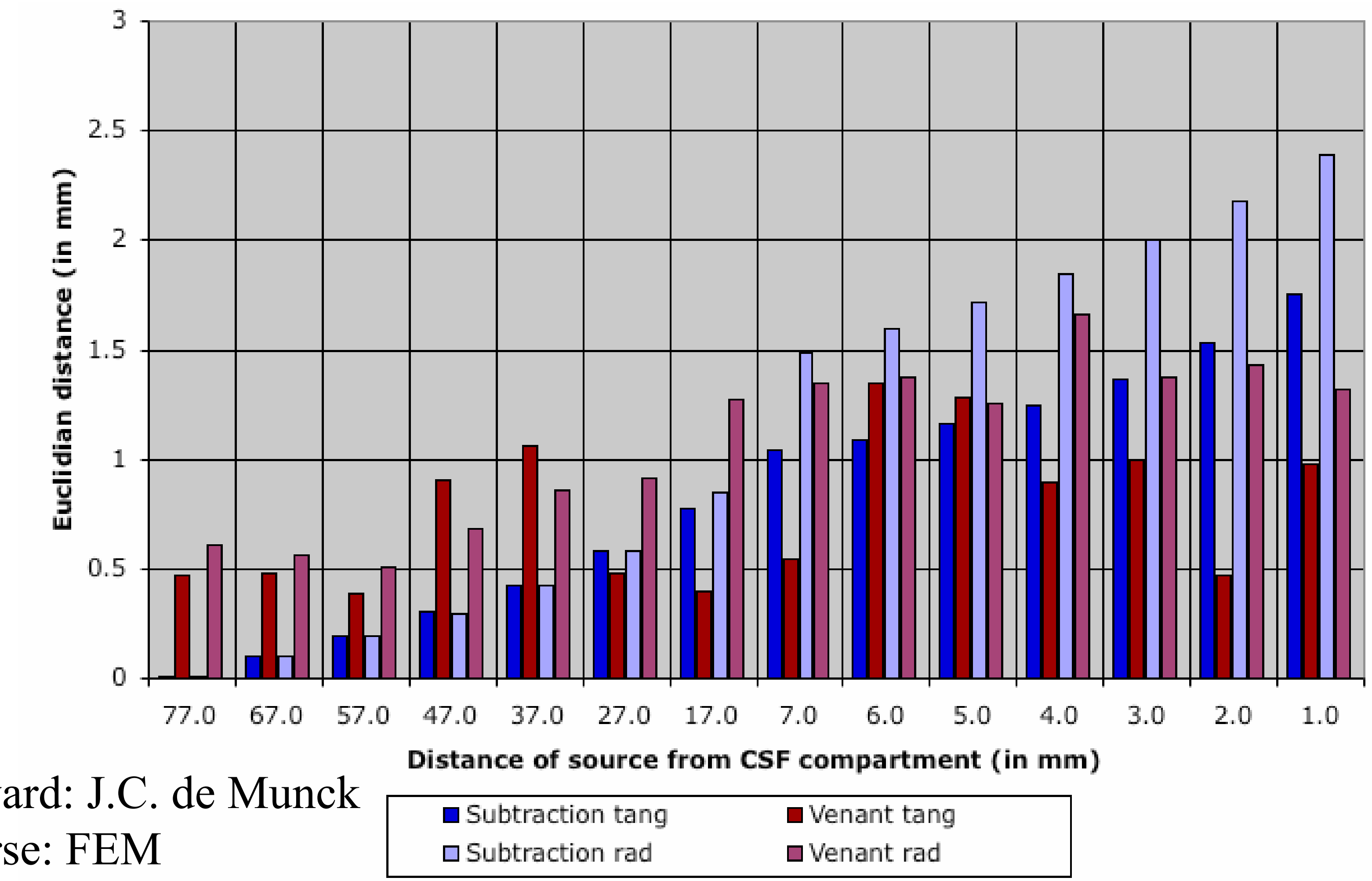
<u>4-layer sphere model:</u>
Radii: 92, 86, 80, 78mm;
0.33, 0.0042:0.042, 1.79, 0.33 S/m

Nodes: 161,086

Wolters et al. *SIAM Journal on Scientific Computing*, in press, 2007

Simulations

Dipole localization error

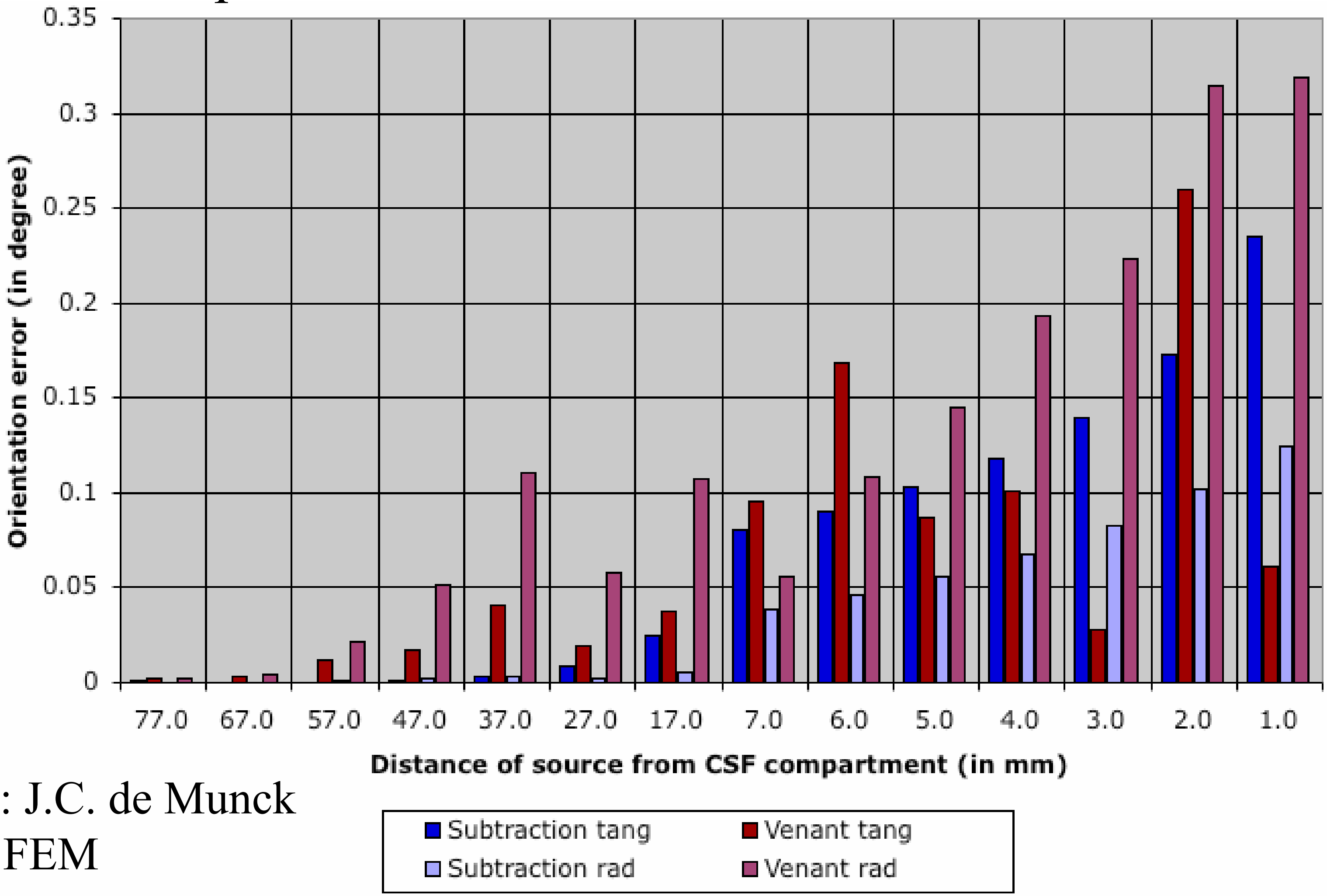


Forward: J.C. de Munck
Inverse: FEM

Wolters et al. *SIAM Journal on Scientific Computing*, in press, 2007

Simulations

Dipole orientation error



Forward: J.C. de Munck
Inverse: FEM

Wolters et al. *SIAM Journal on Scientific Computing*, in press, 2007

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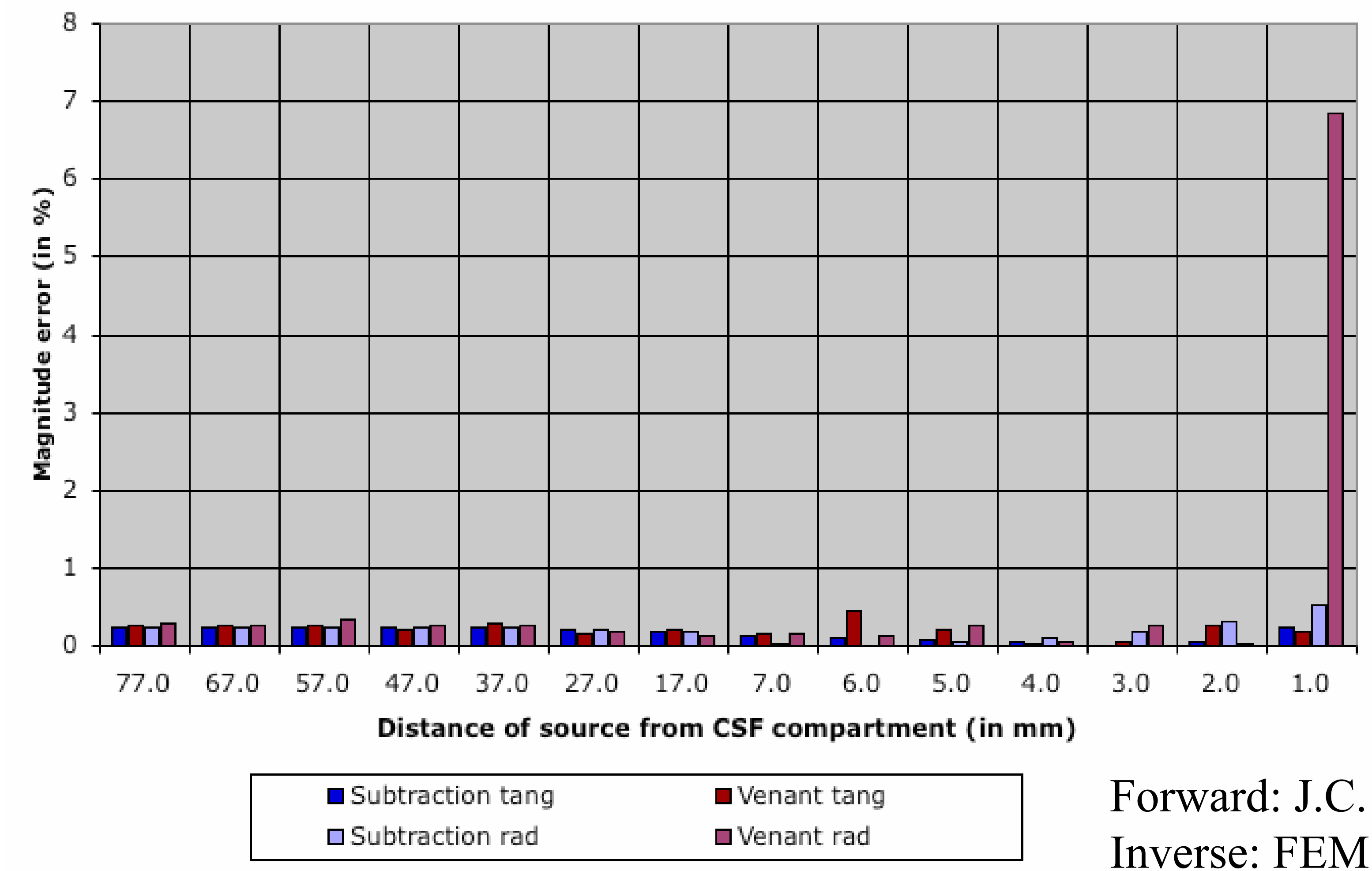
Simulations

Dipole magnitude error



Forward: J.C. de Munck
Inverse: FEM

Wolters et al. *SIAM Journal on Scientific Computing*, in press, 2007

Phantom measurements

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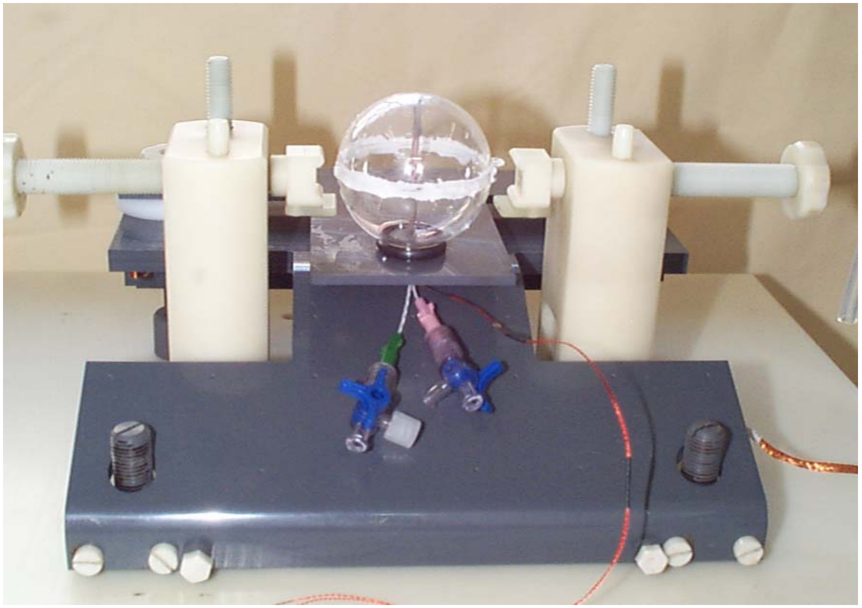

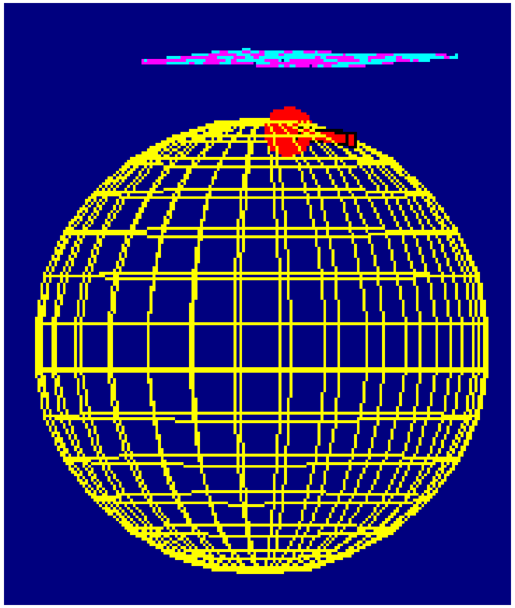

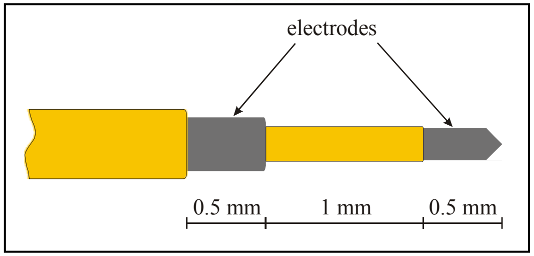

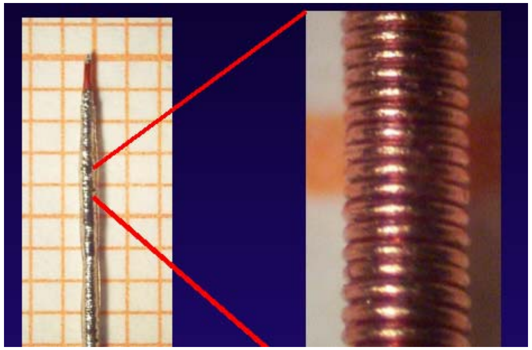

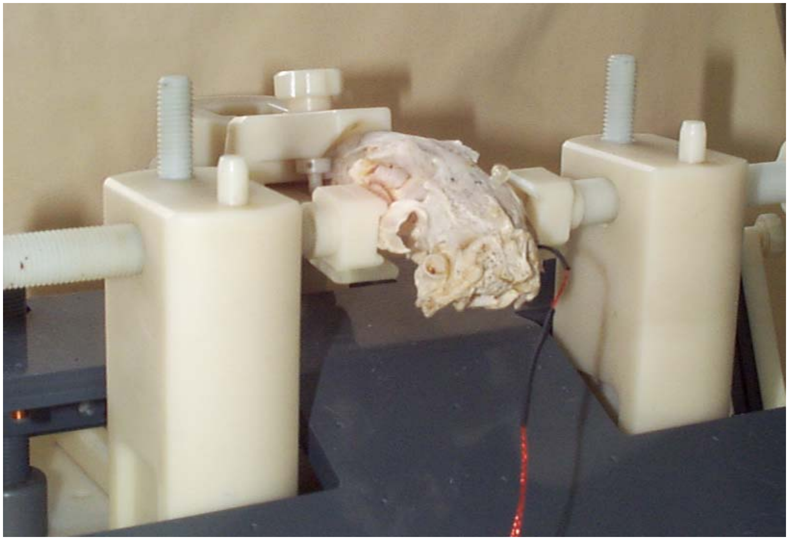

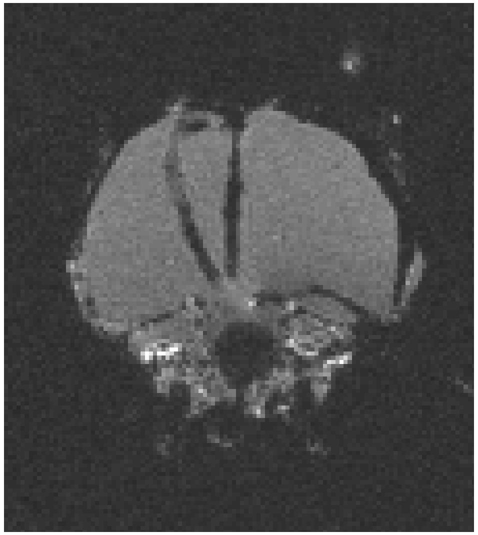

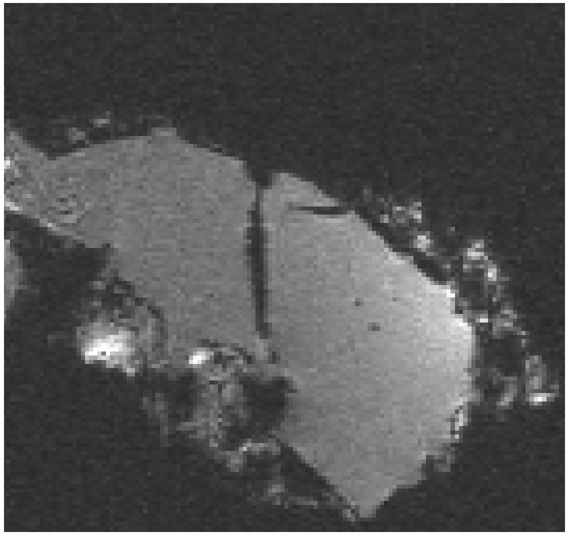

Phantom measurements

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Liehr, Haueisen et al. Annals of Biomedical Engineering, 2005

Phantom measurements

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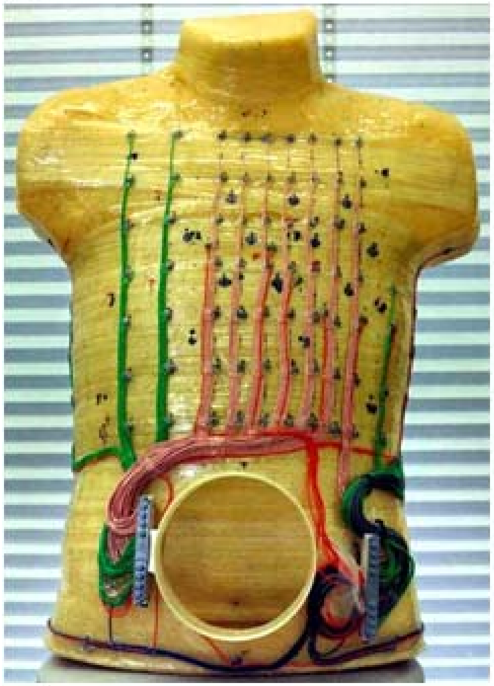
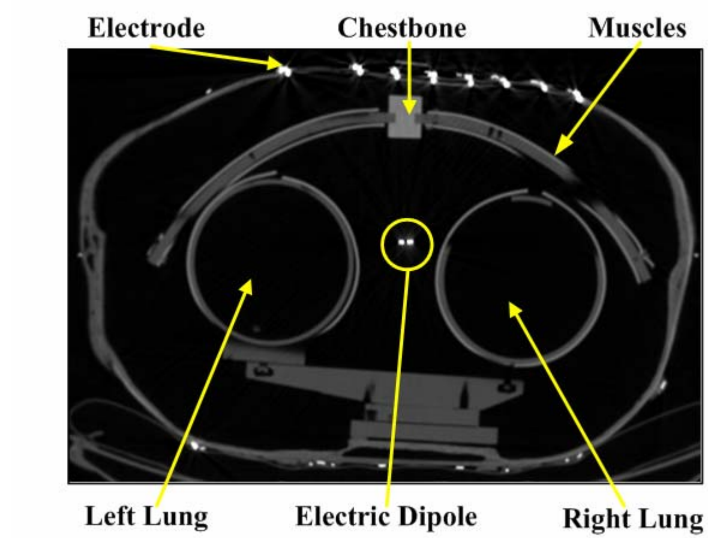
(a)

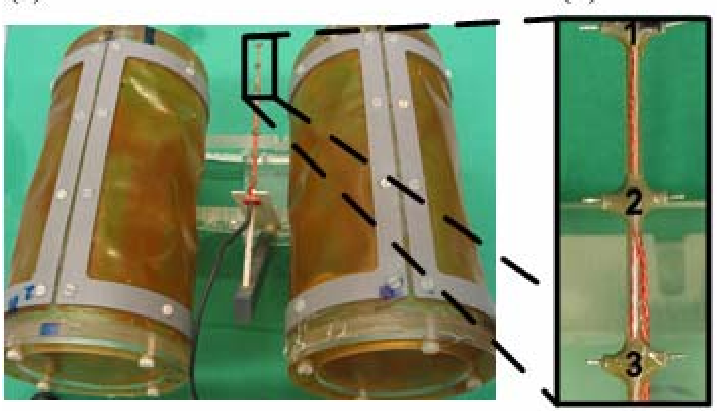


(b)

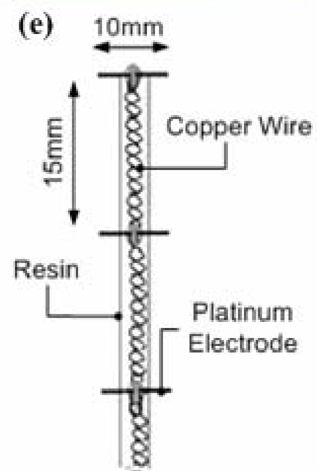


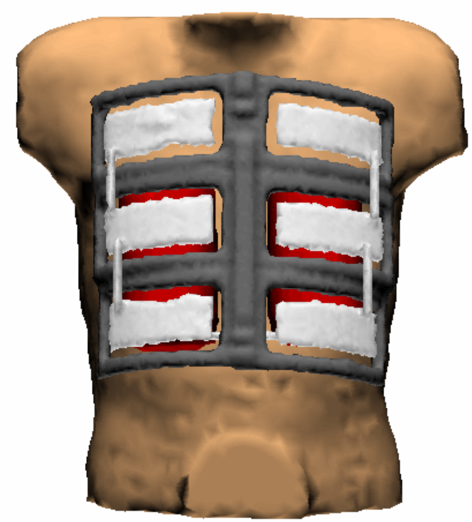
(c)

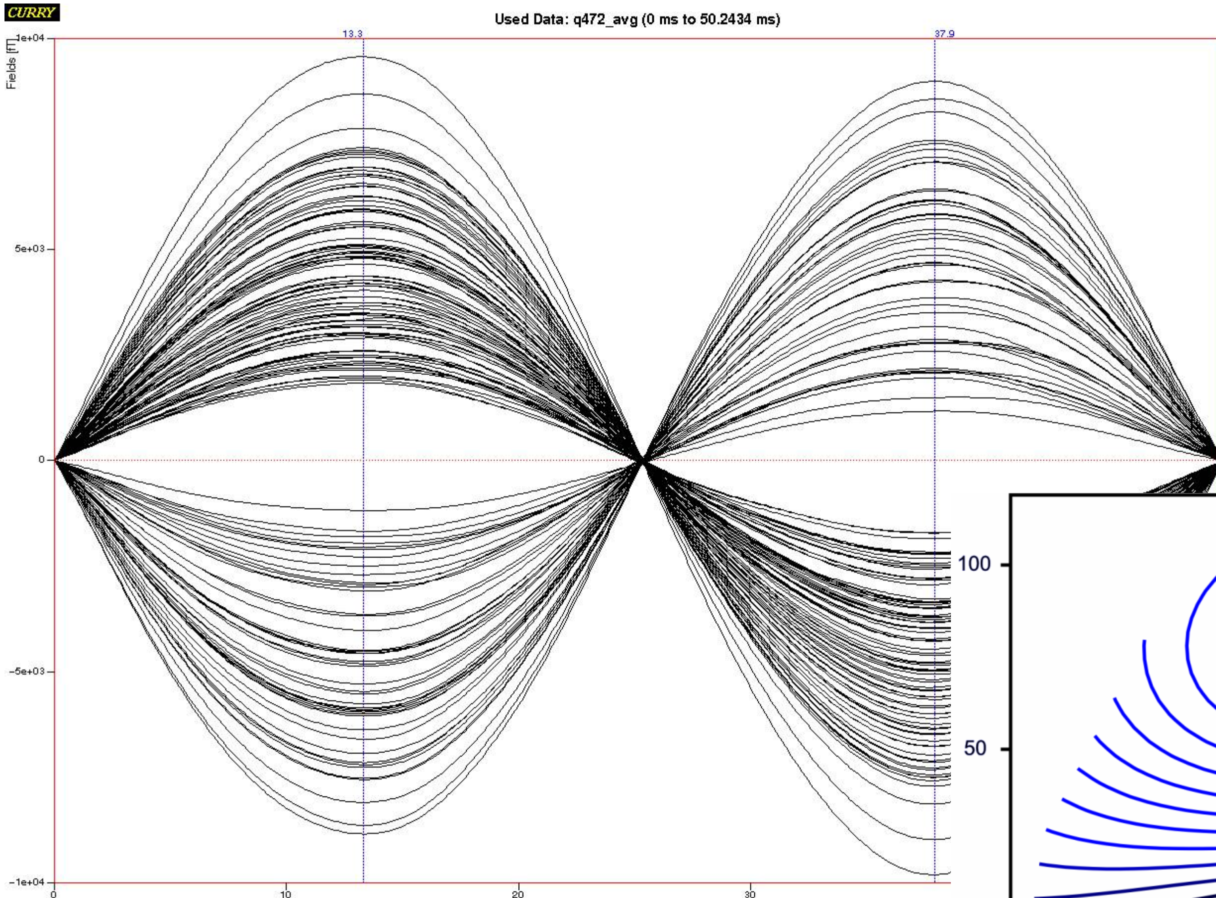
(d)



(e)







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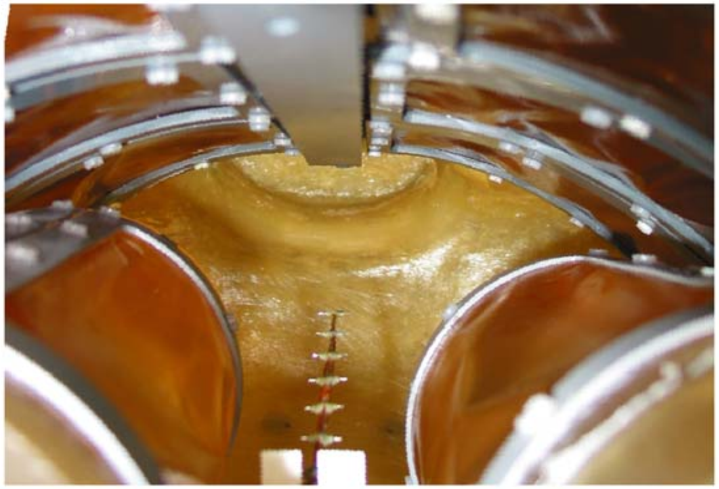
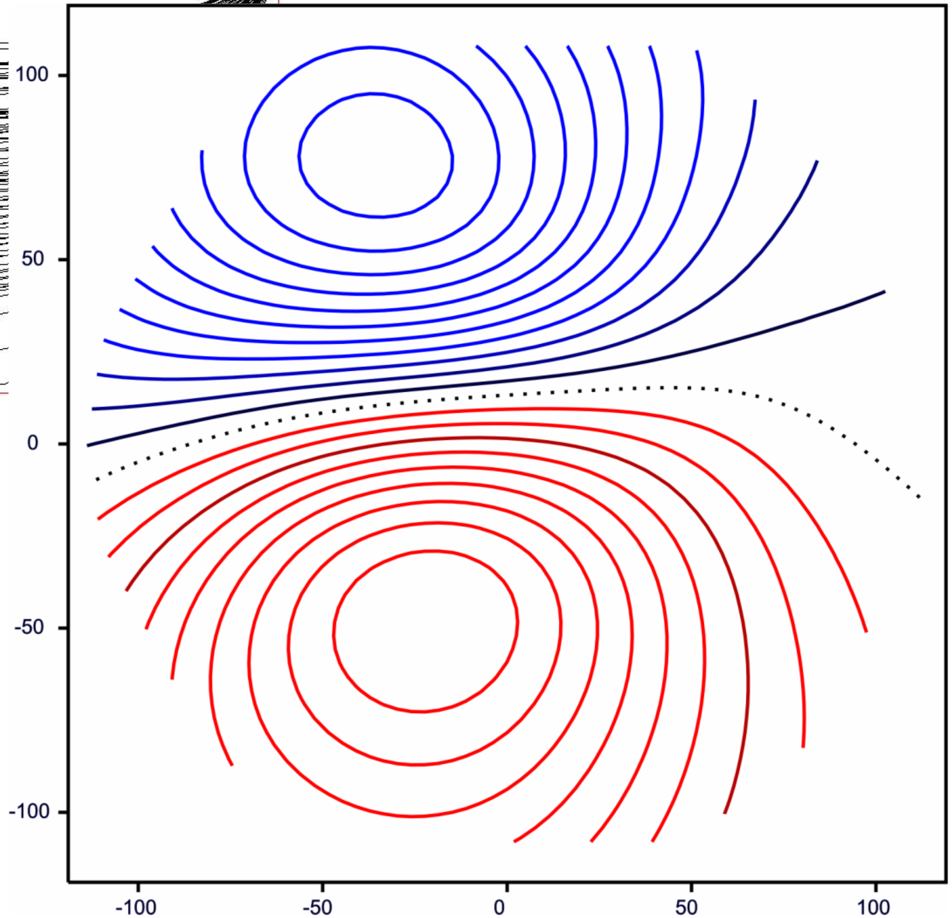
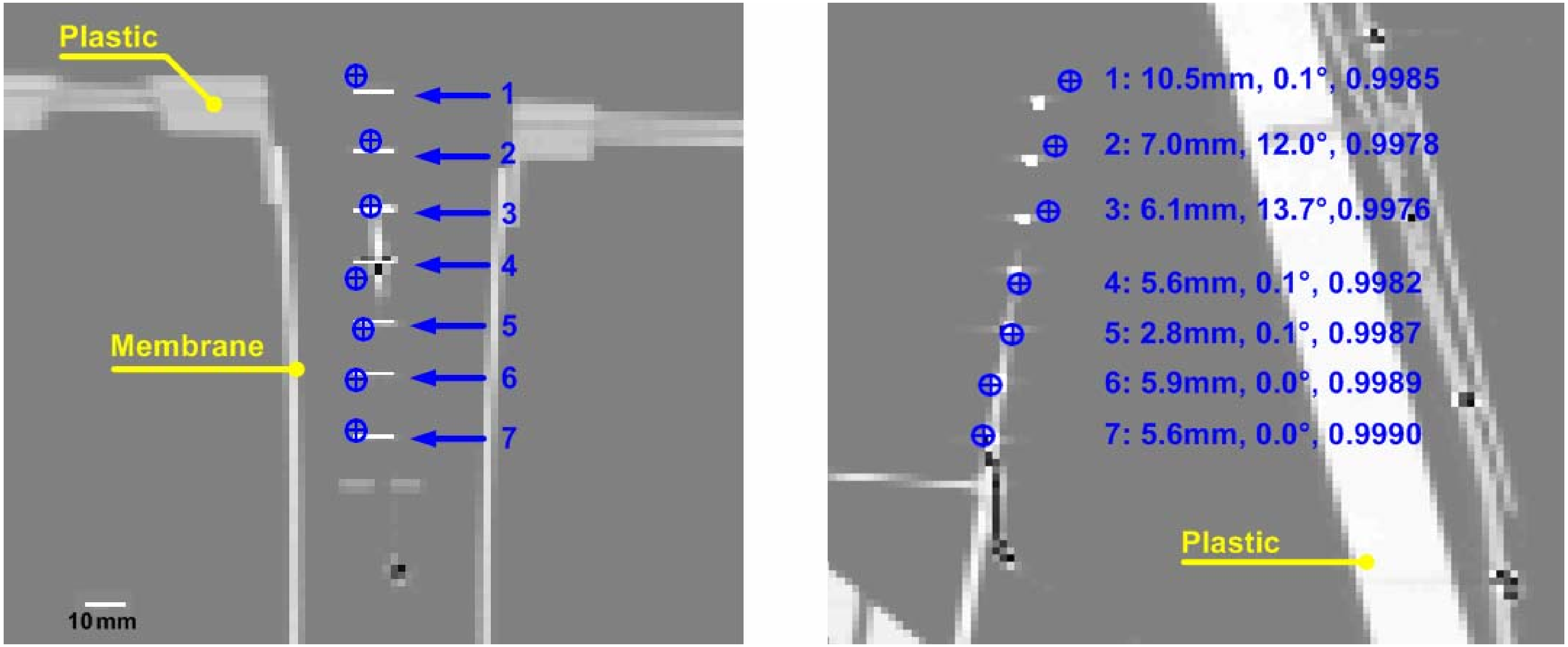




Phantom measurements



Wetterling, Haueisen et al. *IEEE TBME*, in revision, 2008

Animal measurements

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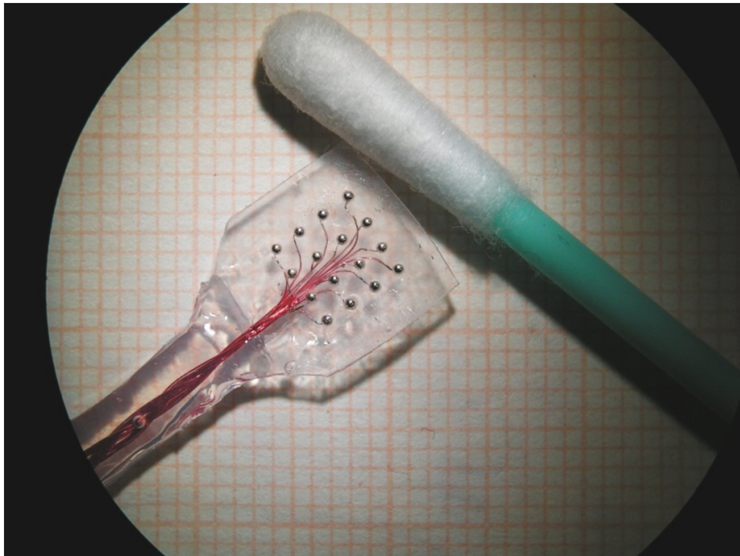
- Combined ECoG and MEG measurements in rabbits
- median nerve / tibial nerve
  - current 0.2 - 0.5 mA
  - Interstimulus interval 503 ms
  - 2048 averages
  - latency
    - 15 - 20 ms (median nerve)
    - 20 - 24 ms (tibial nerve)



Animal measurements

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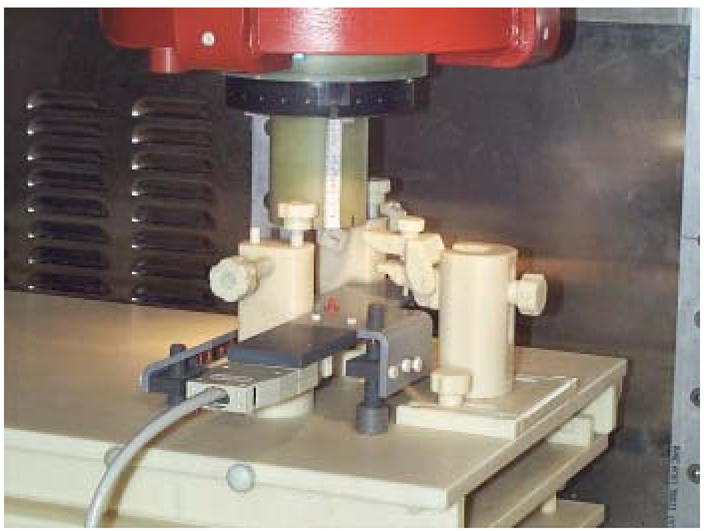

Combined electric measurements (ECoG) with Compumedics Neuroscan Synamps

Animal measurements

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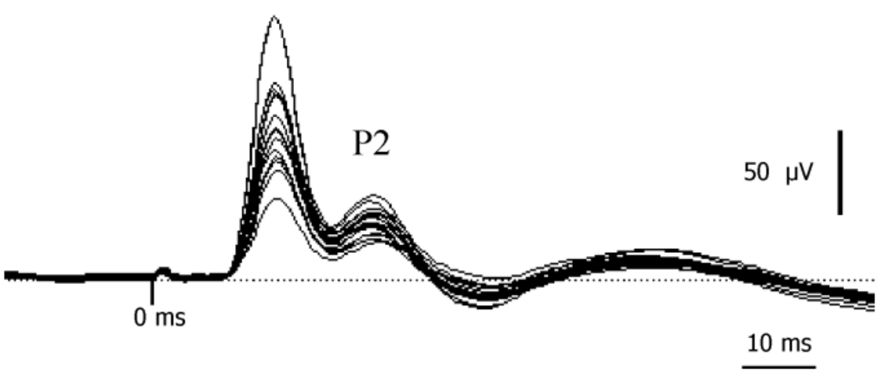
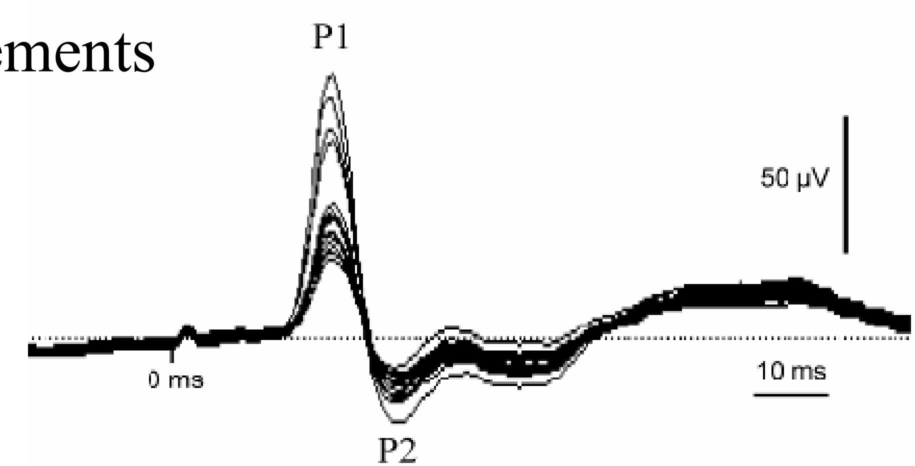
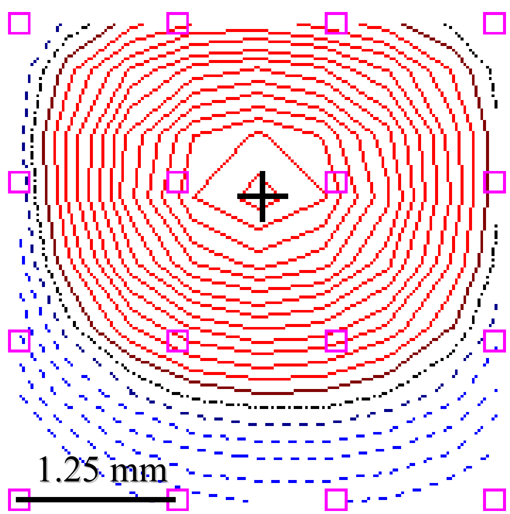
Median nerve

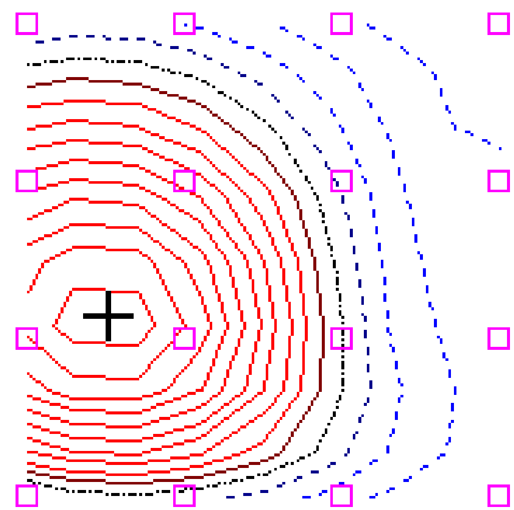
Tibial nerve

Electric measurements









Animal measurements

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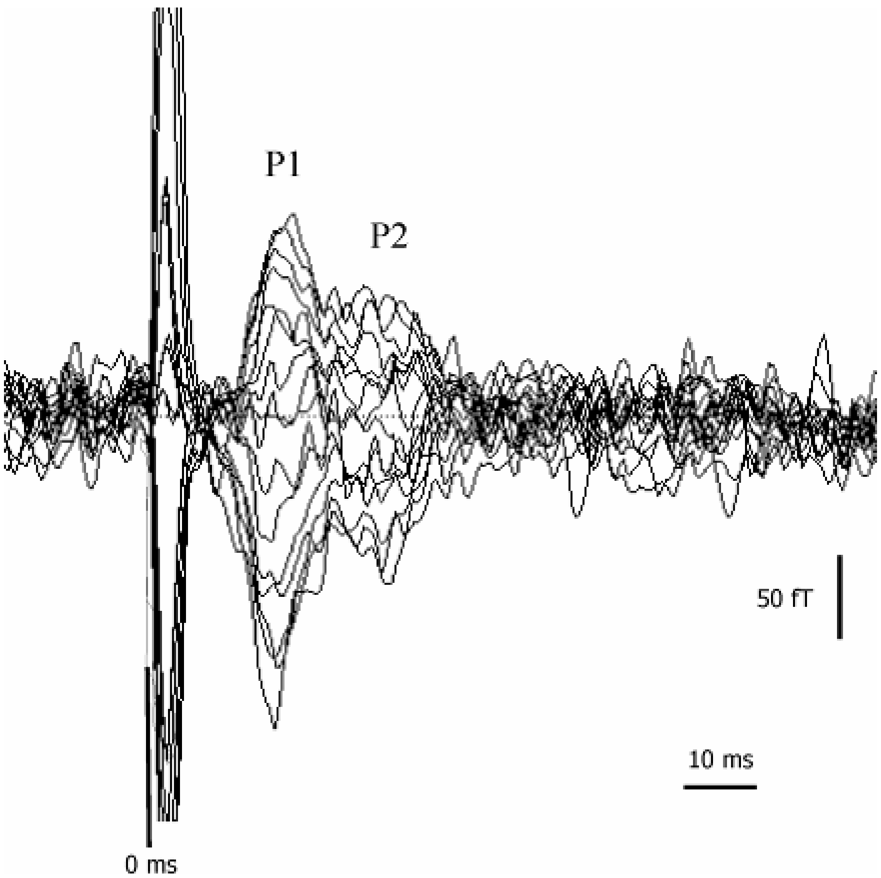
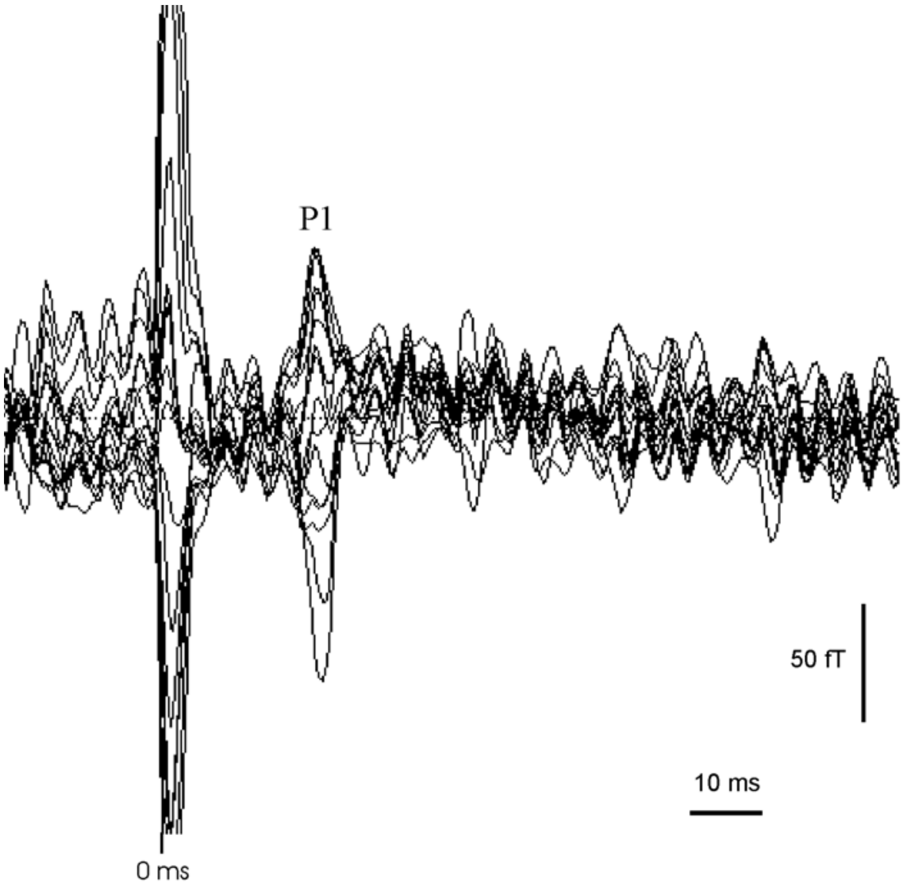
Median nerve



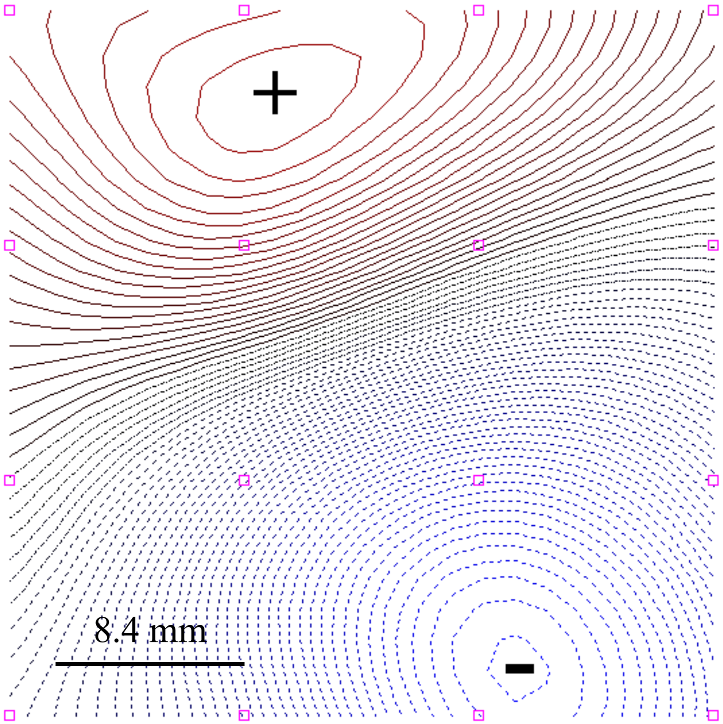
Tibial nerve



Magnetic measurements

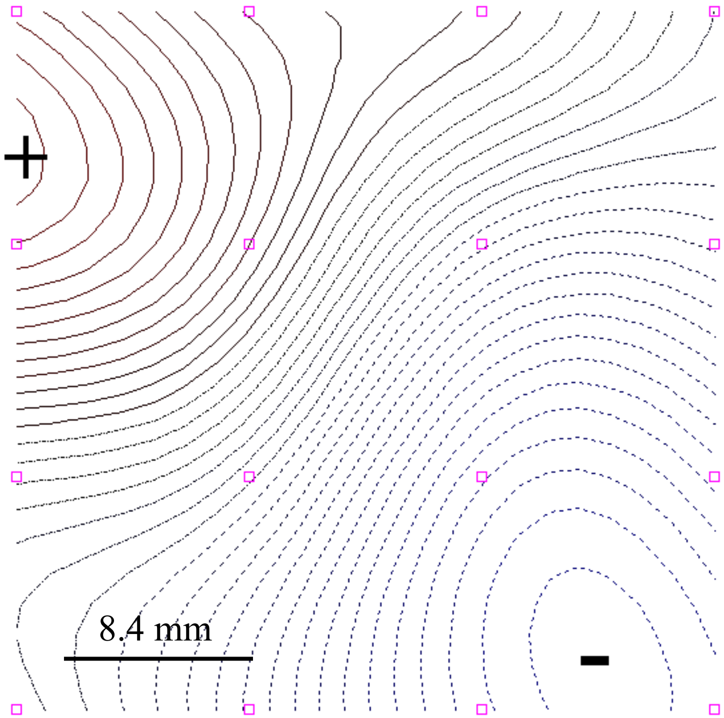
Animal measurements

Median nerve



Time point: 17 ms (P1)
Increment: 5 fT

Tibial nerve



Time point: 21 ms (P1)
Increment: 5 µV

Magnetic measurements

Animal measurements

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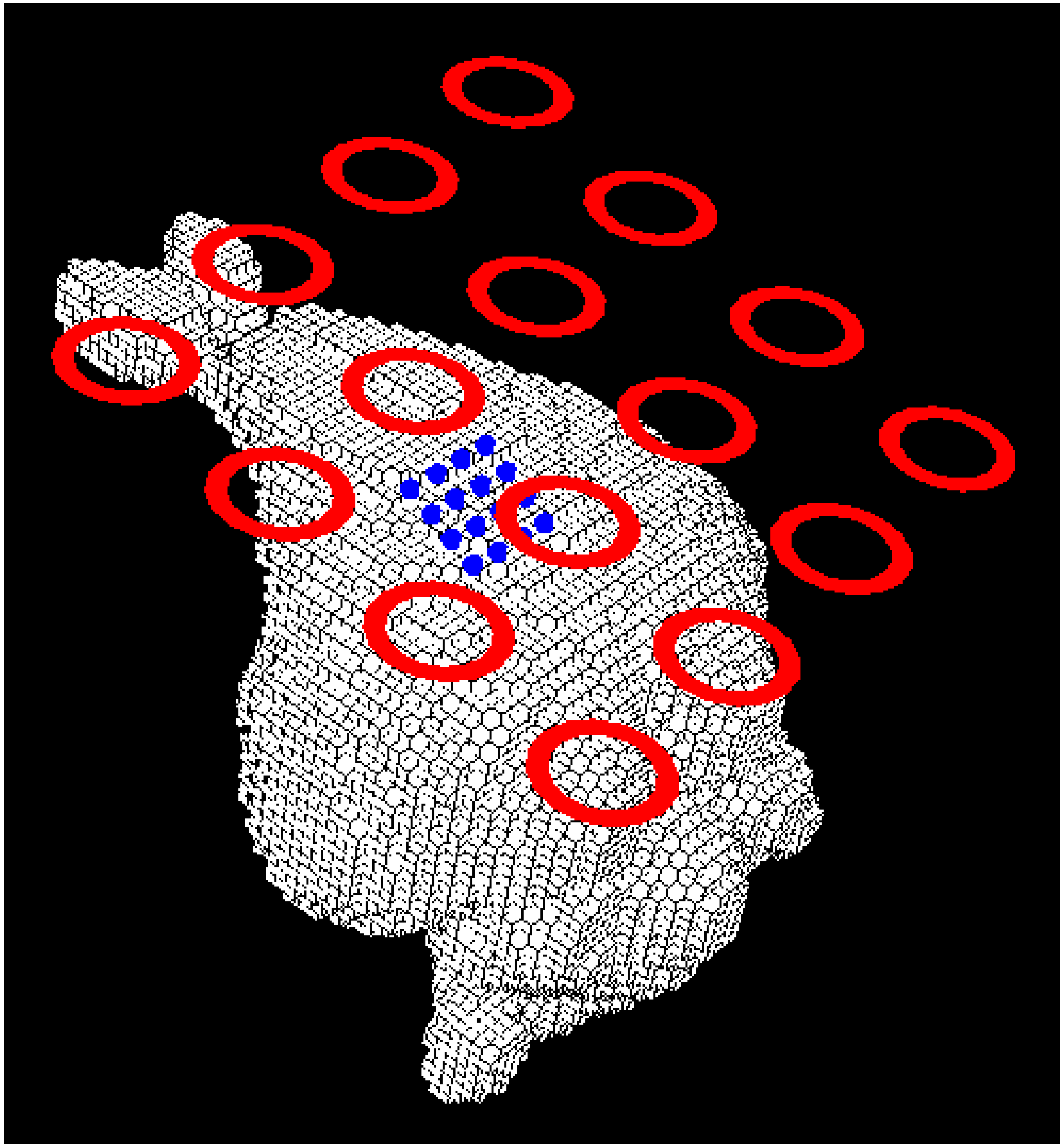
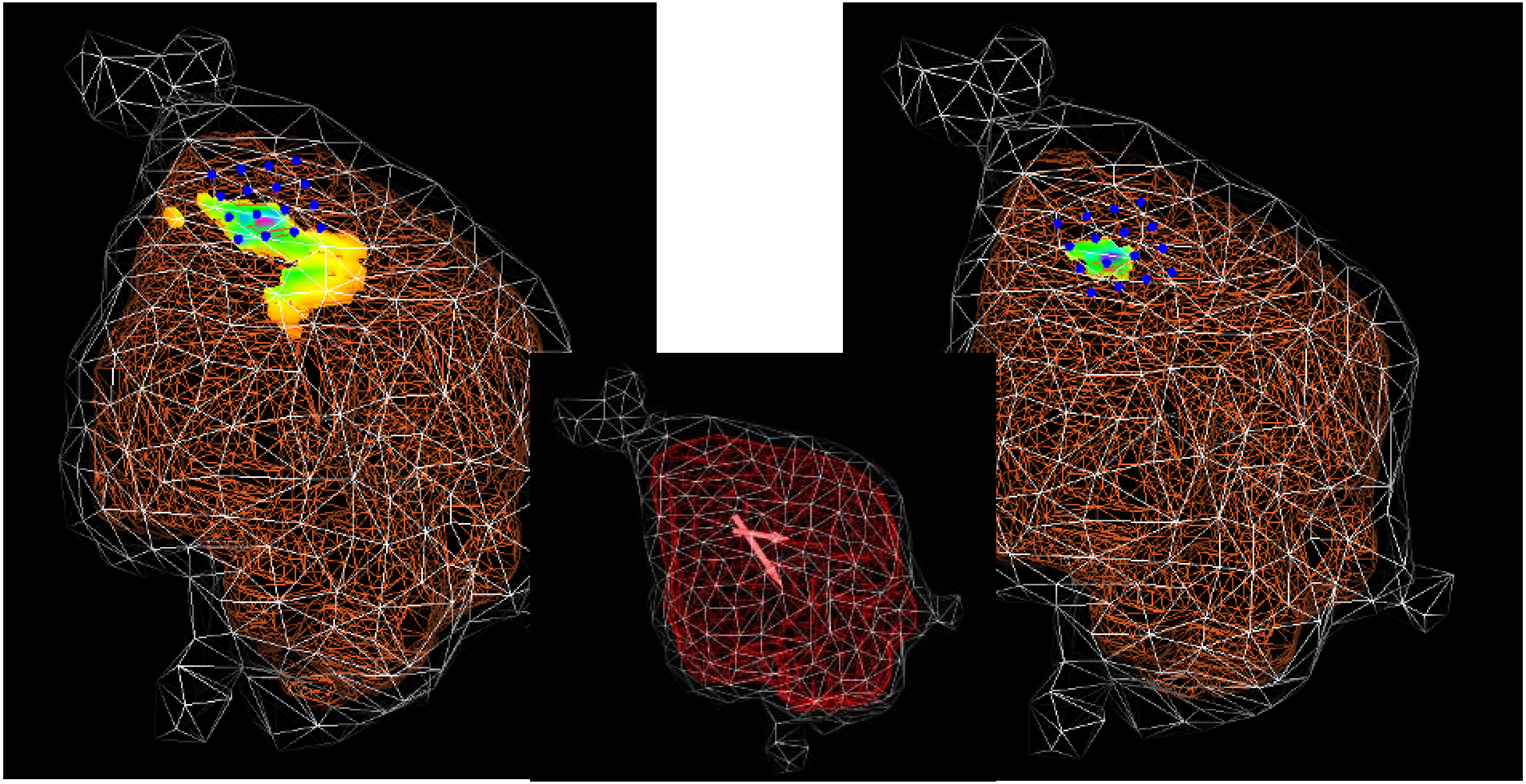
Source localization setup

- 16 MEG pick up coils
- 16 electrodes
- One compartment model



Animal measurements

Comparison median and tibial nerve



dip 1 - median nerve: 44.8/46.6/50.5 mm; dip 2 - tibial nerve: 46.2/48.2/50.3); calculated dipole distance 2.1 mm

Influence of anisotropy

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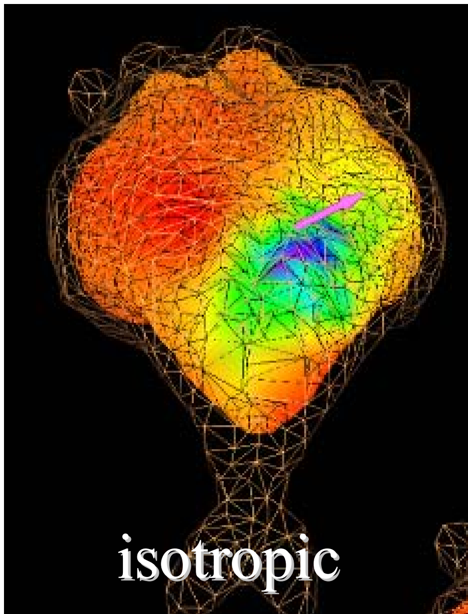
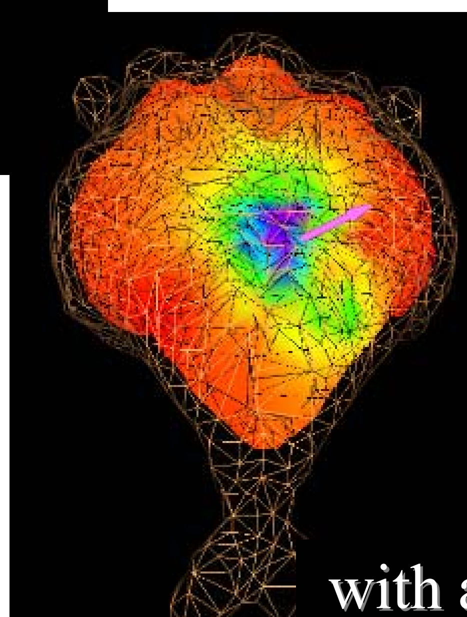
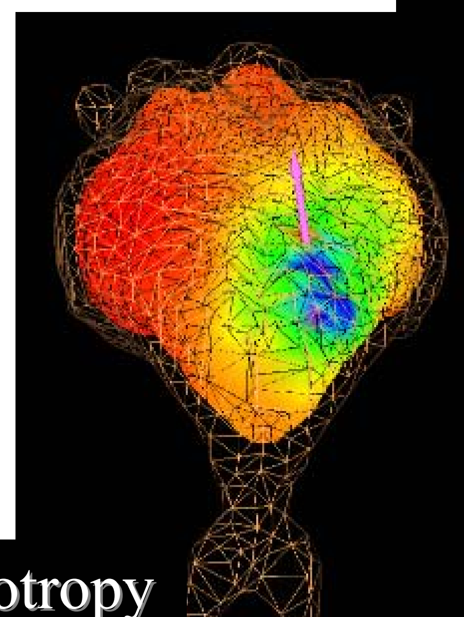
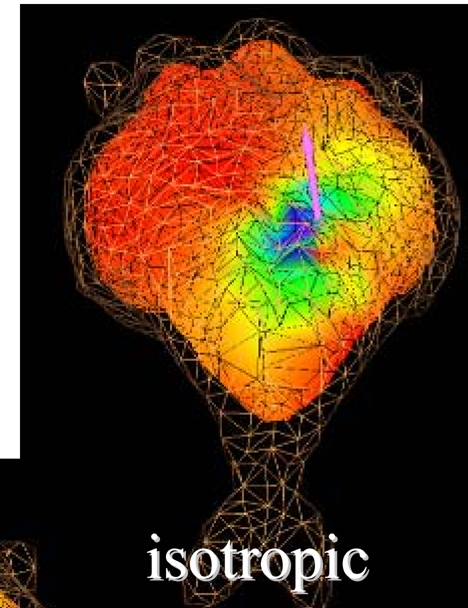
median and tibial nerve









Validation results

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- ✓ **Validation in a spherical model successful**
- ✓ **Validation with two stimulus modalities successful**
- ✓ **Validation BEM and FEM successful**
- ✓ **Influence of anisotropy within the procedural limits for median and tibial nerve stimulation**

Thanks to:

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Yoshio Okada
Ceon Ramon
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David S. Tuch
Van J. Wedeen

The SimBio Team:

Carsten Wolters
Alfred Anwander
Thomas Knösche
Matthias Dümpelmann
…

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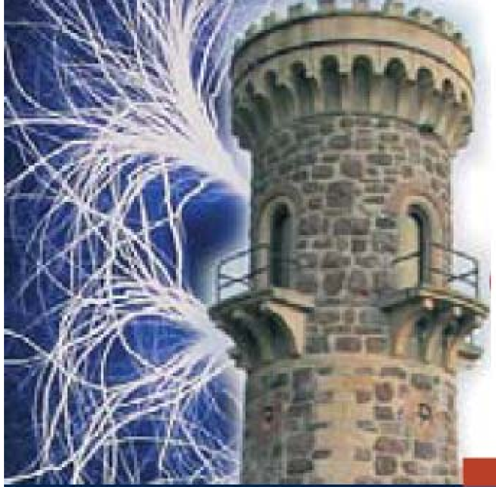

OIPE 2008

10th Workshop on Optimization and Inverse Problems in Electromagnetism

14 – 17 September, 2008,
Ilmenau, Germany