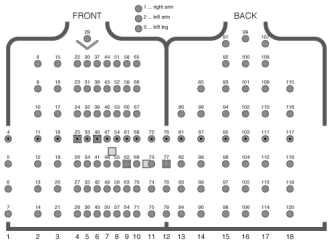
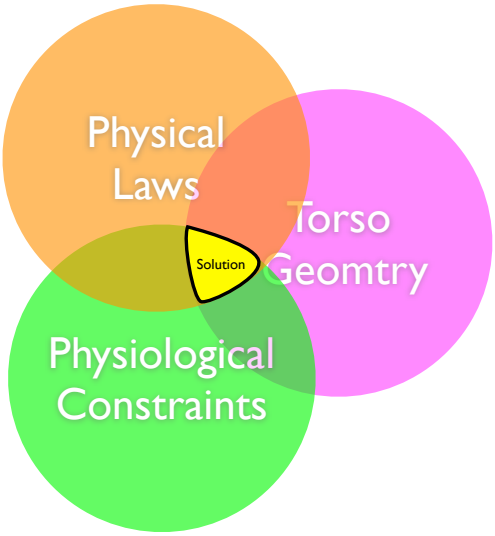
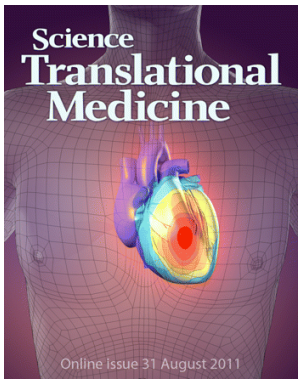
Inverse Problems in Electrocardiography

What is ECGI?

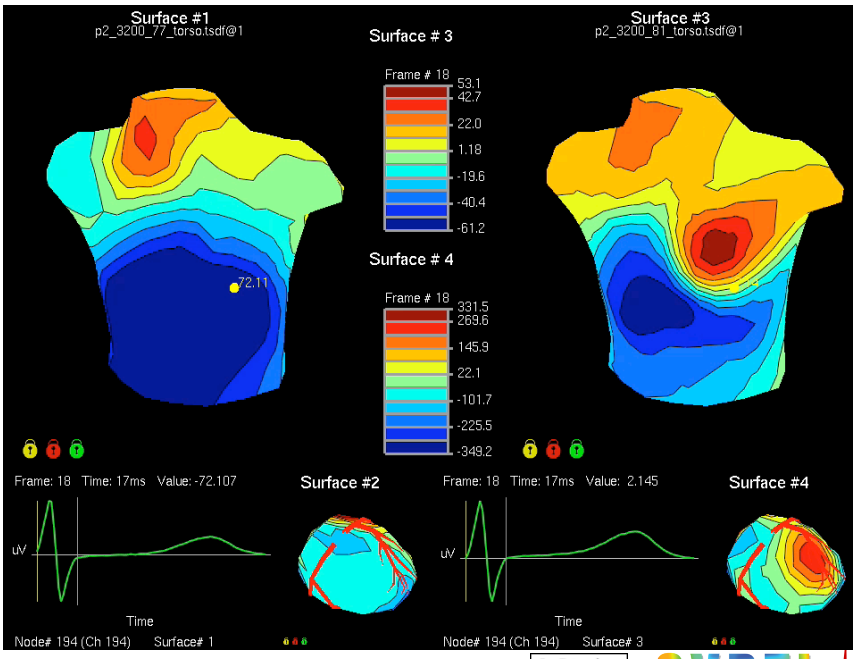


BSPM Electrode Placement



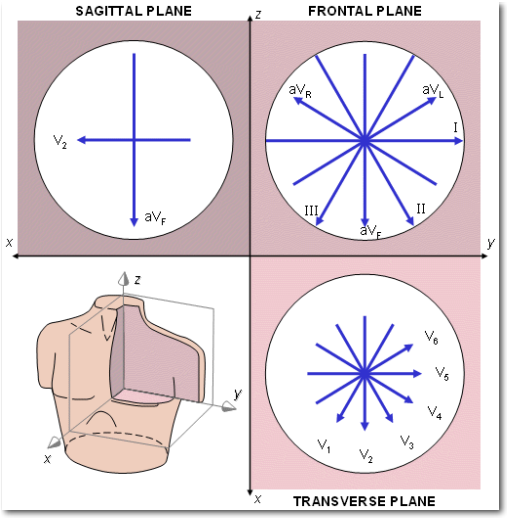


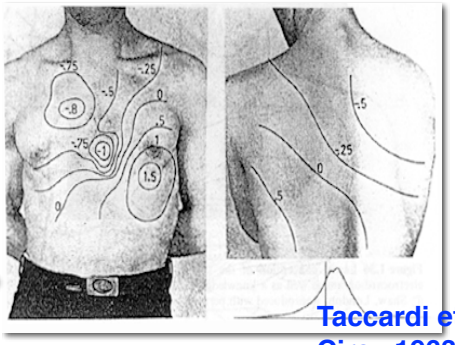
It Works (or It Can Work)



Body Surface Potentials

ECG to BSPM





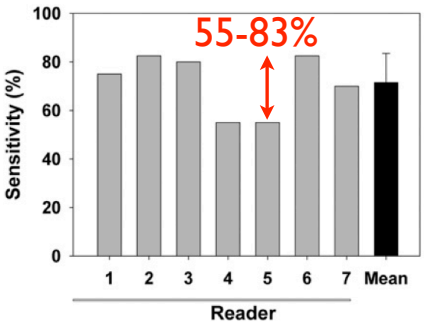
Taccardi et al, Circ., 1963

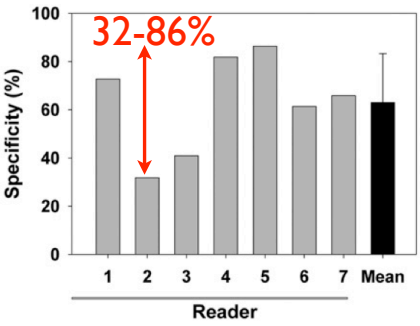
Performance of ECG

Differentiating ST-Elevation Myocardial Infarction from Nonischemic ST-Elevation in Patients With Chest Pain

Viet Tran, MD[a], Henry D. Huang, MD[a], Jose G. Diez, MD[a,b], Gerardo Kalife, MD[b], Rajiv Goswami, MD[a], David Paniagua, MD[a], Hani Jneid, MD[a], James M. Wilson, MD[a,b], Scott R. Sherron, MD[b], and Yochai Birnbaum, MD[a,b,*]

J Cardiol 2011;108:1096–1101





More Leads = More Information

Mechanisms of the Spatial Distribution of QT Intervals on the Epicardial and Body Surfaces

BONNIE B. PUNSKE, PH.D., ROBERT L. LUX, PH.D., ROBERT S. MACLEOD, PH.D., MARC S. FULLER, PH.D., PHILIP R. ERSHLER, PH.D., THEODORE J. DUSTMAN, M.E., YONILD VYHMEISTER, M.S., and BRUNO TACCARDI, MD, PH.D.

J. Cardiovasc. Electrophys. Volume 9, Issue 7, pages 773–786, July 1998

Adv Cardiol. 1978;21:36-9.
Criteria for localizing preexcited areas from body surface maps in Wolff-Parkinson-White patients.
De Ambroggi L, Taccardi B, Macchi E, Perotta GM.

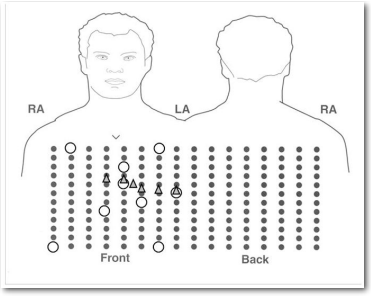
Body surface mapping during percutaneous transluminal coronary angioplasty. QRS changes indicating regional myocardial conduction delay
H Spekhorst, A SippensGroenewegen, GK David, MJ Janse and AJ Dunning

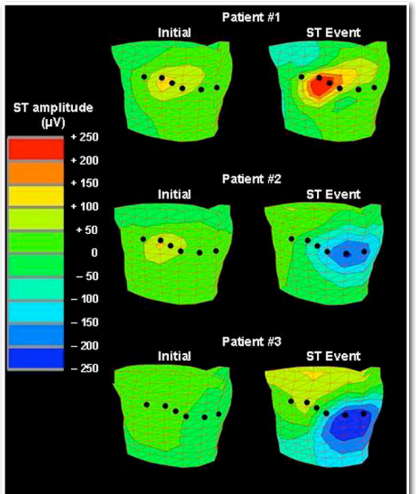
Circulation 1990, 81:840-849

Example

Estimated body surface potential maps in emergency department patients with unrecognized transient myocardial ischemia☆

Barbara J. Drew, RN, PhD,[a,b,*] Daniel M. Schindler, RN, MS,[a] Jessica K. Zegre, RN, MS,[a] Kirsten E. Fleischmann, MD,[b] Robert L. Lux, PhD[c]





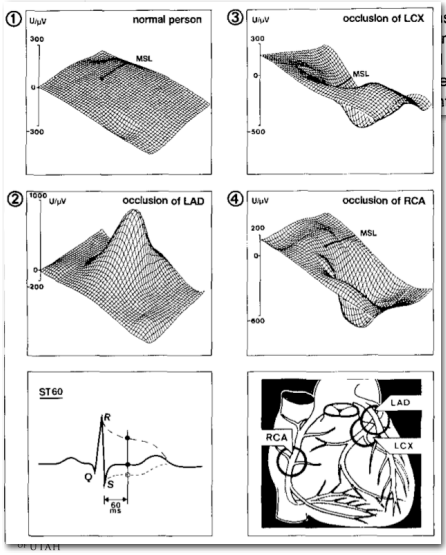
PTCA Example

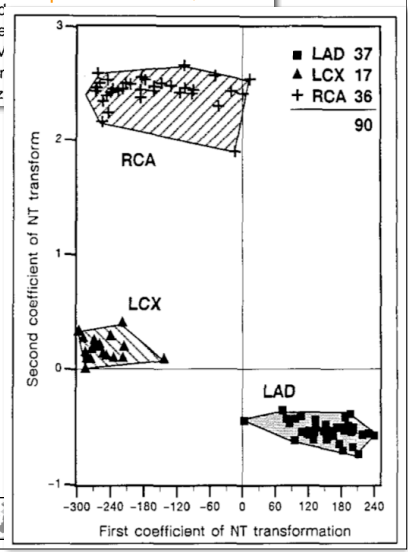
VALIDATION OF BODY SURFACE POTENTIAL MAPPING DURING THROMBOLYSIS: MULTI–CENTRE STUDY BY MEANS OF A COMMUNICATION COMPUTER NETWORK

L. Vogt, J. Silny, G. Rau, S. Effert,
R. Uebis[1], R. von Essen[2], H. Just[3], J. Meyer[4]

stitute for Biomedical Engineering and
rnal Medicine I, University of Aache
Medicine I, Stiftsklinik Augustinum, M
ernal Medicine III, University of Freibur
ternal Medicine II, University of Mainz

Computers in Cardiol., 1989





How Much Information?

How Many Leads Are Necessary for a Reliable Reconstruction of Surface Potentials During Atrial Fibrillation?

María de la Salud Guillem, Andreas Bollmann, Andreu M. Climent, Daniela Husser, Jose Millet-Roig, and Francisco Castells

IEEE Transactions on Information Technology in Biomedicine, 2009, 13, 3, 330

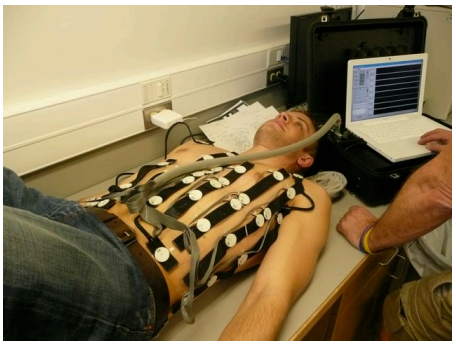
Standardization of reduced and optimal lead sets for continuous electrocardiogram monitoring: where do we stand?

Barbara J. Drew, PhD,[a,*] Dewar D. Finlay, PhD[b]

[a]*Department of Physiological Nursing, University of California San Francisco, San Francisco, CA, USA*
[b]*School of Computing and Mathematics and Computer Science Research Institute, University of Ulster, Northern Ireland, UK*

J Electrocardiol. 2008;41(6):458–465.

More Leads = More Time

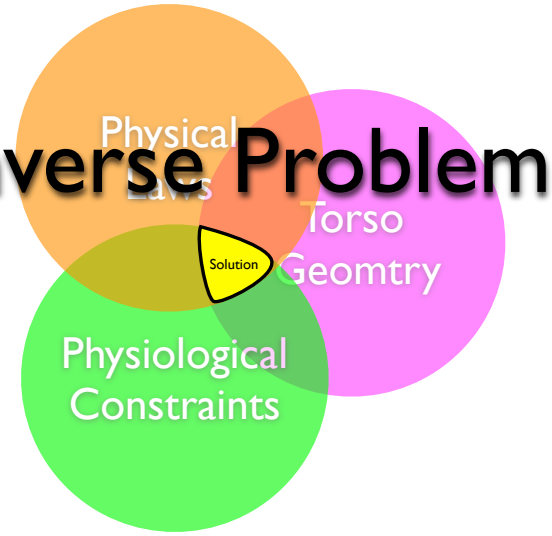


BSPM Summary

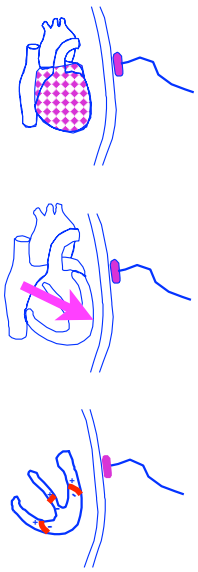
- "...reliability and test performance of body surface mapping in CAD is promising"
- " The limited evidence that is available demonstrates proof of concept..."
- "Further research is needed to better characterize the performance characteristics of these devices...."

Aetna Clinical Policy Bulletin: Body Surface Potential Mapping, 2010.

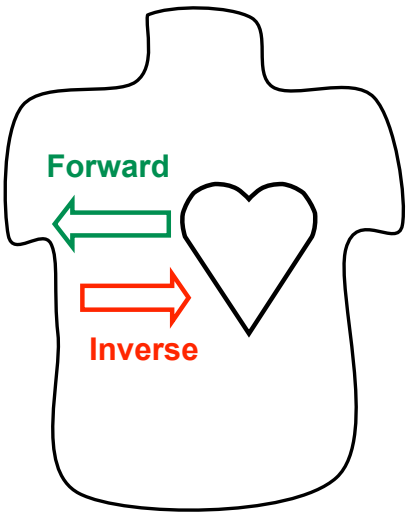
Inverse Problem



Bioelectric Field Problem Basics

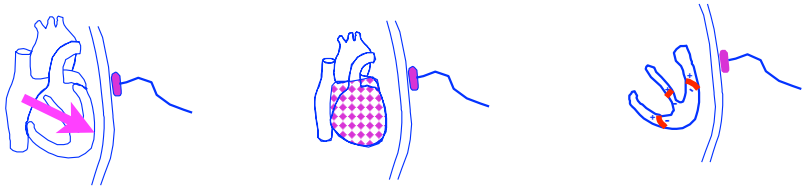


Source



Volume Conductor Model

Sources

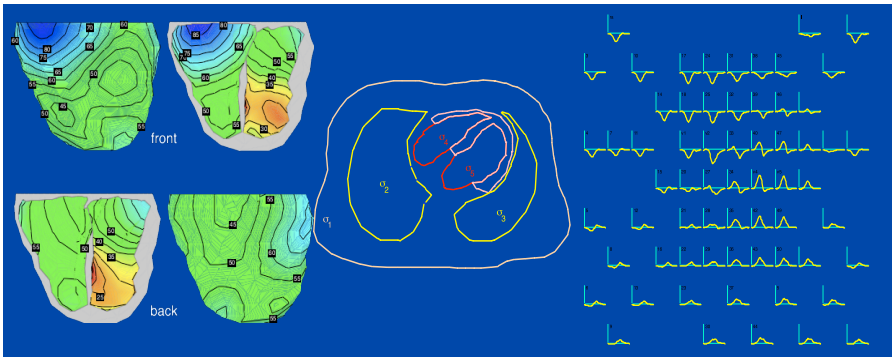


Dipole	Epicardial Potentials	Epi-Endocardial Activation Time
Simple, few leads, conventional	Measurable, comprehensive, unique	Measurable, clinically directly useful
Not unique, not measurable, requires assumptions, misses details	Interpretation ambiguous, complex, ill-posed	Uniqueness unclear, tenuous assumptions, ill-posed

Activation

Forward problem

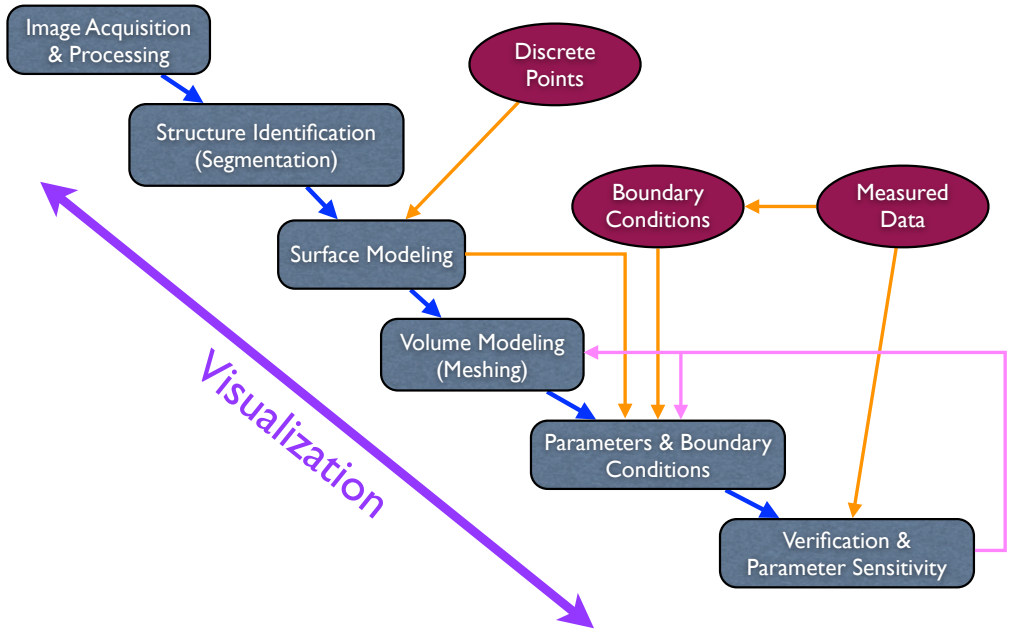
Epicardial/Endocardial Activation Time → **Geometric Model** → **Body Surface Potentials**



Inverse problem

Thom Oostendorp, Univ. of Nijmegen

How To Solve an Inverse Problem

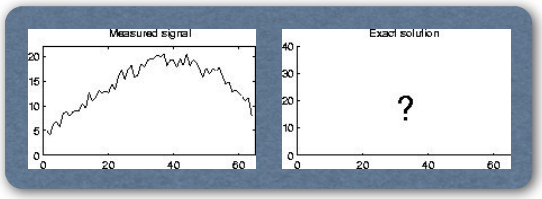


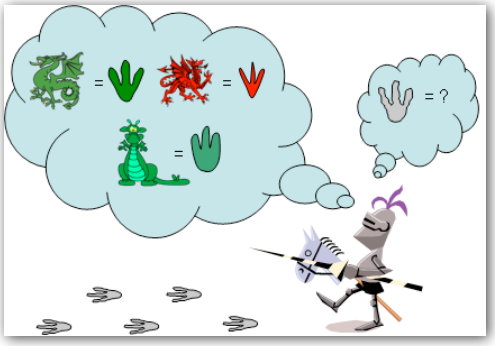
What Does Ill-Posed Mean?

✓ A solution exists

✓ The solution is unique

✓ The solution depends continuously on the data, in some reasonable topology.

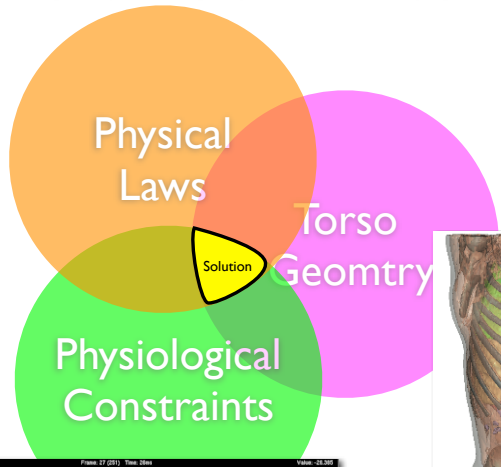


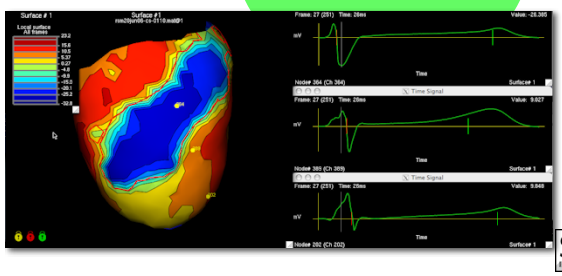


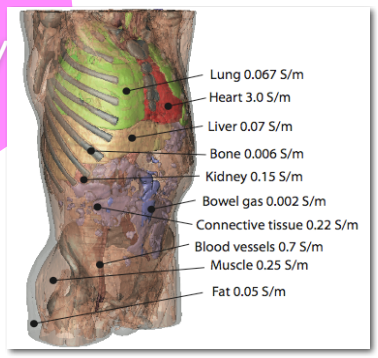
Constraints

$$\nabla^2 \phi = -\frac{I_v}{\sigma}$$

$$\nabla^2 \phi = 0$$







Applying Constraints

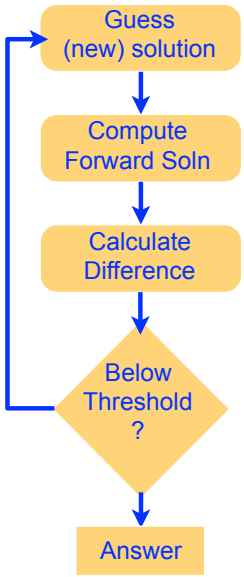
Closed Form

$$x_\lambda = \arg\min_x (||y - Ax||^2 + \lambda^2 ||Mx||^2)$$

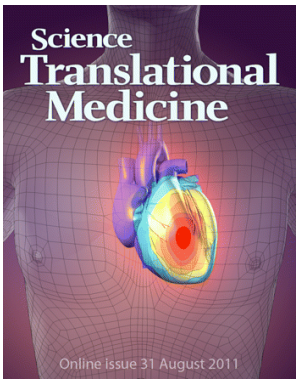
with solution

$$x_\lambda = (A^T A + \lambda M)^{-1} A^T y$$

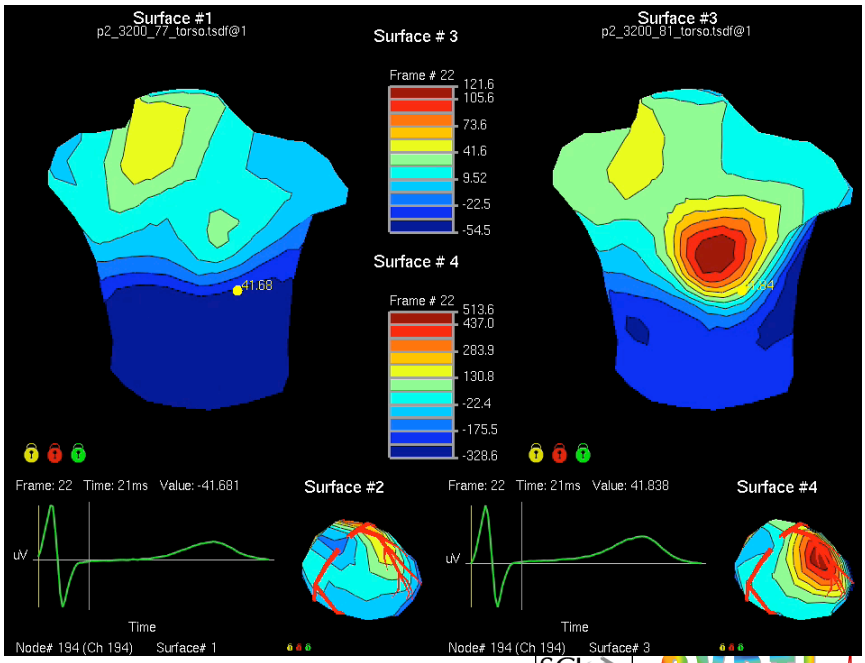
Iterative



Results



Acute Ischemia

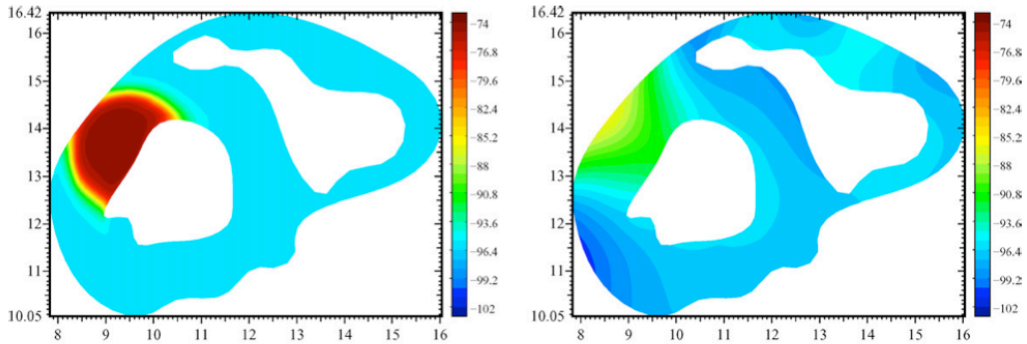


On the possibility for computing the transmembrane potential in the heart with a one shot method: An inverse problem

Bjørn Fredrik Nielsen [a,b,*], Xing Cai [a,b], Marius Lysaker [a]

[a] *Simula Research Laboratory, P.O. Box 134, N-1325 Lysaker, Norway*
[b] *Department of Informatics, University of Oslo, P.O. Box 1080, Blindern, N-0316 Oslo, Norway*

Mathematical Biosciences. 2007;210(2):523–553.

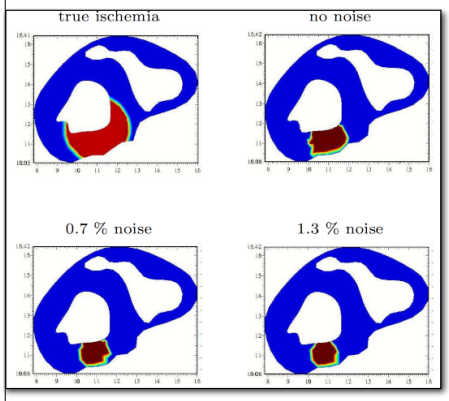


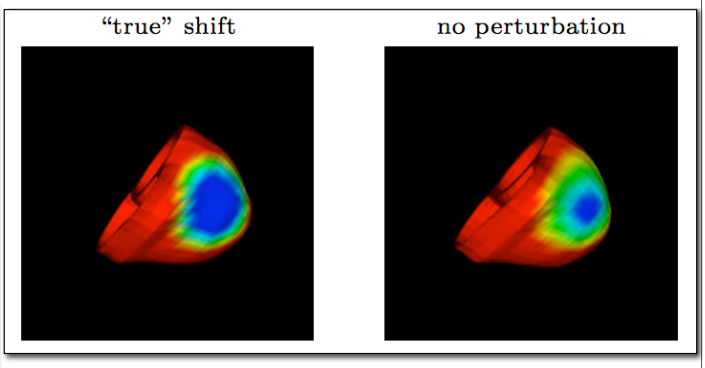
(a) v_{true} (b) Solution v_{oneshot}

CAN ECG RECORDINGS AND MATHEMATICS TELL THE CONDITION OF YOUR HEART?

Bjørn Fredrik Nielsen, Marius Lysaker, Per Grøttum, Kent-André Mardal, Aslak Tveito, Christian Tarrou, Kristina Hermann Haugaa, Andreas Abildgaard, and Jan Gunnar Fjeld

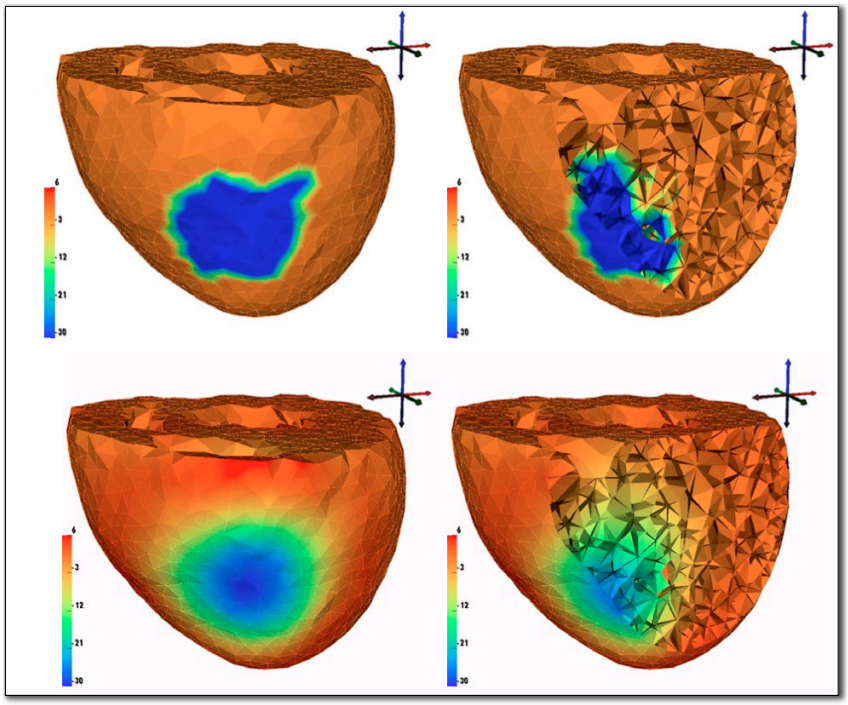
SIMULA RESEARCH LABORATORY
2010, Part 2, 287-319





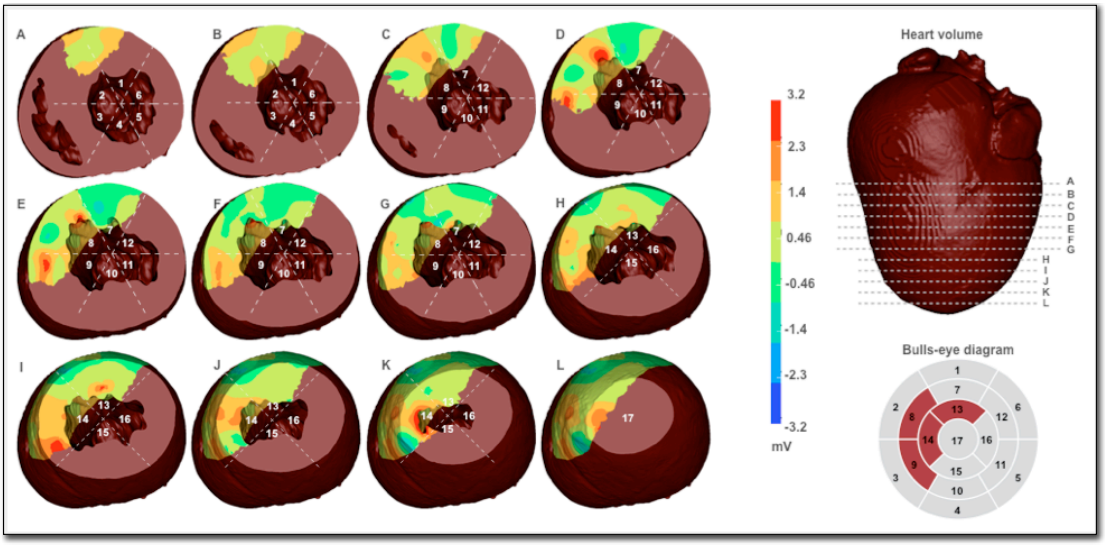
True

Inverse Computed



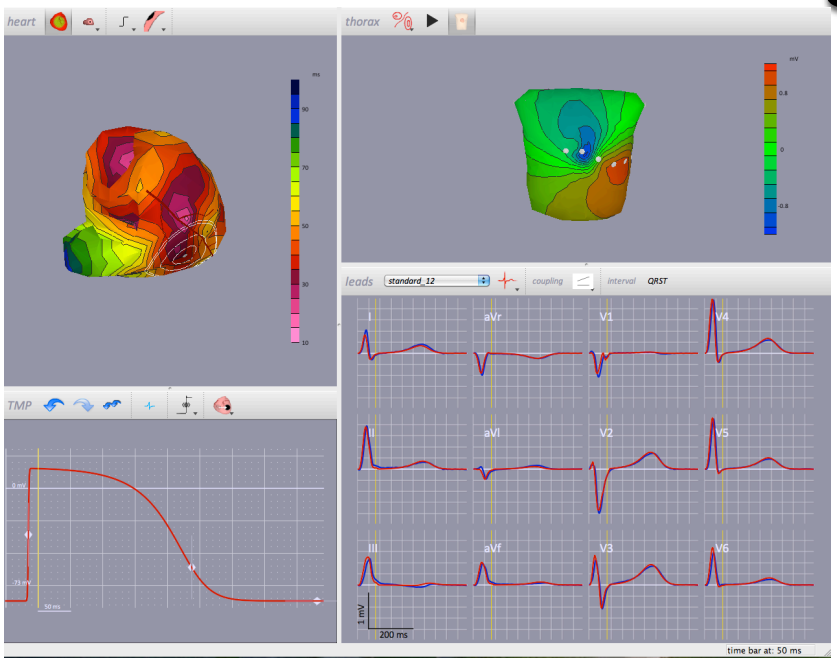
Dafang, Kirby, Johnson, Macleod, Unpublished Results

Measurements



Aras, Swenson, Burton, Macleod. Unpublished Results

Tools for Learning



ECGSim

www.ecgsim.org