Advanced Modeling and Visualization of Cardiothoracic Electrical Fields

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Problem. Major tools for clinical diagnosis of cardiac diseases are electrocardiographic techniques. Intra- and extracorporal electrical measurements are applied to gain knowledge concerning the activity of a patient's heart. The measurements deliver electrograms, which are commonly examined by medical experts and provide the basis for diagnosis. Promising techniques for clinical use are those, which apply methods of surface visualization to represent a large number of measured electrograms and derived quantities, e.g. body surface potential mapping [1], epicardial and endocardial mapping [2]. Furthermore, these techniques can be used in conjunction with computer-based anatomical and electrical models leading to principally new diagnosis methods.

In this abstract we will introduce several novel techniques for modeling and visualization of cardiothoracic electrical fields. The modeling techniques aim at improving accuracy and applicability of simulations, the visualization techniques at providing novel insights into results of simulations.

Methods. Numerical calculation of thoracic electrical fields created by cardiac sources, the so-called forward problem in electrocardiology, necessitates knowledge of the distribution of conductivity. Commonly, medical imaging data are applied to produce anatomical models, which are transformed to conductivity models.

Our framework for modeling (SCIRun/BioPSE [3], [4]) is based upon finite element techniques, which allow for inhomogeneity and anisotropy of conductivity in the thorax to be taken into account. We extended the framework by including high-order finite element techniques. Additionally, stochastic finite elements were developed for quantifying uncertainty in the forward problem. The underlying mathematical theory provides means of assessing statistical quantities such as mean and variance of a solution based upon known statistical moments of input data, e.g. mean and variance of potential on the heart and conductivity of the system.

We developed novel visualization techniques for representing electrical fields. An automated technique for placement of seed points to generate streamlines guarantees in a statistical sense that the density of electrical streamlines is proportional to the electrical current density. A streamsurface technique is used to capture the continuous behavior of the three-dimensional electrical current field through a curvilinear front integrated along the flow. An optimal resolution is adaptively determined to account for the local geometric characteristic of the field, resulting in smooth surfaces. A further technique extracts the topology of current fields constrained to the cardiac surface. This yields the global

structure of tangential flow, segmenting the heart surface into regions, where streamlines exhibit homogeneous patterns.

Results. We provide examples of the utility of high-order finite element solutions for solving the forward problem. We present recent work on the use of stochastic finite elements. We applied the former described techniques to create exemplary visualizations.

Conclusion and Discussion. The presented techniques for modeling offer advances in comparison to the established methods. High-order elements emit exponential convergence behavior for smooth solutions. This translates to being able to solve forward problems more accurately with less degrees of freedom. Stochastic finite element techniques provide enhanced applicability of forward modeling in electrocardiology by quantifying uncertainty. A combination of both techniques will offer further numerical benefits.

The presented streamline and -surface techniques allow us to provide both intuitive and accurate visualizations of the interconnection between sinks and sources located on the cardiac surface through the current defined over the torso. The visualization of topological structure on the cardiac surface offers new insights into mechanisms of electrical field generation in the thorax and genesis of physiological and pathophysiological electrocardiograms.

References

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