NICE: Noninvasive Imaging of Cardiac Electrophysiology

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Noninvasive Imaging of Cardiac Electrophysiology (NICE) provides in a noninvasive way information about electrical excitation of the heart. The simultaneous acquisition of electrocardiographic (ECG) mapping data with 3D anatomical information from an individual patient enables noninvasive imaging of the electrical function in the heart.

In our bidomain theory based surface heart model formulation the primary electrical source in the cardiac muscle is the spatio-temporal distribution of the so-called transmembrane potential (TMP). Applying bioelectromagnetic field theory, the potential on the chest surface is related to TMP by a second-kind Fredholm integral equation. Thus, a compact operator maps TMP onto the ECG mapping data. Consequently, the determination of these sources from ECG mapping data constitutes a linear inverse ill-posed problem. The nonlinear relationship between activation time (AT), the onset of the typical upstroke of the TMP during depolarization, and TMP makes the problem nonlinear. The inverse procedure is inherently unstable unless physiologically meaningful and valid constraints can be imposed.

For the reconstruction of surface TMP patterns, we use 2nd order Tikhonov regularization in the spatial domain. In the temporal domain monotonic non-decreasing behavior of the potential is presumed. This is formulated as side condition without the need of any regularization parameter. We obtain a linearly constrained sparse large-scale convex optimization problem solved by a fast interior point optimizer. The nonlinear problem (AT imaging) is solved by a sequence of linearized ill-posed problems. These linearized ill-posed problems are solved by employing special spatio-temporal regularization (2nd order Tikhonov regularization in combination with a characteristic template function of TMP). The regularization parameter is determined by the L-curve method. An initial guess is calculated by the so-called critical point theorem. A volume conductor model is constructed from the individual magnetic resonance imaging data set. A commercial software package is used for contour detection and segmentation followed by mesh optimization based on a Delaunay algorithm. The shape and the distribution of the triangles play an important role, especially for boundary element calculations, in order to achieve good numerical performance. TMP imaging and AT imaging are compared with each other concerning computational burden, regularization parameter determination, and several physiological constraints of the excitation of the heart.

Our findings demonstrate that accurate non-invasive imaging of atrial and ventricular ectopic beats as well as pre-excited activation in man is feasible under clinical conditions. The atrial and ventricular AT imaging results are very promising and give hope that further research will bring this new diagnostic tool closer to clinical applications.