Defibrillation Optimisation via Huygens Subgridding for Finite-Difference Time-Domain Method

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In Europe 700,000 deaths per year are caused by cardiac arrest. Electrical defibrillation is the only effective therapy for cardiac arrest rhythms. Successful defibrillation depends on the body size, defibrillator electrode size, shape and placement, and the electrode-to-skin coupling material. Latest Resuscitation Guidelines (A.J. Handley, Resuscitation Council (UK), 2005) state the need for detailed studies of a current-based defibrillation.

Since conducting defibrillator device experiments in vivo is unethical and impractical, presented research offers a computational electrodynamics framework to optimise defibrillator parameters. Traditionally, wave propagation in human body is simulated with the Finite-Difference Time-Domain (FDTD) method. To obtain quality propagation results within fine geometry of human organs, high resolution FDTD grid is required everywhere in the simulation domain. Due to Courant criterion small spatial step in FDTD grid demands a small temporal step. But FDTD simulation with high spatio-temporal resolution is computationally expensive. Better efficiency is reported in a few works, that apply subgridding schemes. Subgridding splits the computation domain into coarse and fine grids with independent spatial and temporal steps. Courant criterion is maintained for coarse and fine grids separately. Subgridding saves computational resources applying high resolution grid only around fine geometric features. Common subgridding schemes use low subgridding ratios of 2 to 3 and allow only basic material traverse, insufficient to represent the dielectric properties of human tissues.

Novelty of presented research is the application of Huygens Subgridding (HSG) to the Frequency Dependent–Finite-Difference Time-Domain (FD–FDTD) method for an electromagnetic wave simulation inside the human torso. Huygens Subgridding (J.-P. Bérenger, IEEE Trans. Antennas Propag., pp. 3797–3804, 2005), adopted in this work, is a promising subgridding algorithm with no theoretical limit on subgridding ratio and little reflection from the subgridding interface. To account for the human tissues' frequency response, the normal FDTD method was extended to Frequency Dependency with the Auxiliary Differential Equation approach using the 1st order Debye relaxation model.

Practical experiments with human heart inside of the fine grid and subgridding ratio of 5 were conducted in this work. Numerical results validate the exactness of the HSG–FD–FDTD method and demonstrate its ability to solve practical problems such as defibrillation optimisation. Simulation with the HSG–FD–FDTD method took only 17–19% of the time required by the reference fine grid FD–FDTD code.