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Exploring the mechanism of Low energy defibrillation using parallel GPU computing

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Background

Low-energy anti-fibrillation pacing (LEAP) utilizes multiple low-strength shocks instead of one strong shock to maintain the defibrillation success rate while lowering the energy needed hence reduces the tissue damage and pain for patients. When electric shocks are applied, excitations, or virtual electrodes, are generated at the boundary of conductive heterogeneities such as blood vessels, fibers and bundles. Each additional shock recruits more heterogeneities to gradually synchronize the whole tissue. The mechanism of LEAP is not fully understood and improvement can be made by varying multiple parameters such as the electrode shapes and timing of shocks. By using computational models, these parameters are easily adjusted and can minimize the necessity of animal experiments.

Methods

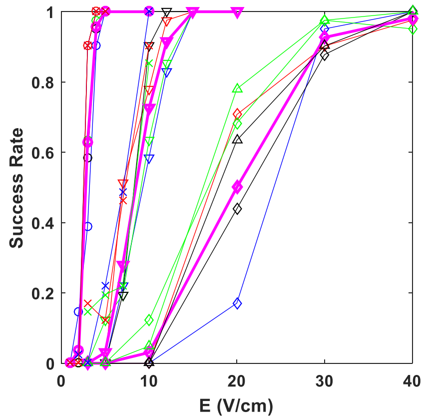
To achieve real-time simulations on realistic heart geometry, Web Graphic Library (WebGL), a parallel GPU programing language, is used to simulate the human atrial model (Ten Tusscher 2012) on 2D and a phenomenological model (Fenton Karma) on 3D domains. In the 2D simulation, a square domain with multiple unexcitable circles randomly distributed represent a slice of cardiac tissue with low-conductive blood vessels. The size distribution of blood vessels follows a power law obtained from experiments. The 3D simulation runs on the structure of a section of canine left ventricle with embedded coronary vessels obtained through micro-CT scans. In both 2D and 3D, shocks are delivered with two parallel plane electrodes. We also simulated the situation that the shocks are delivered by one point electrode and one surface electrode with a plane/convex/concave shape.

Results

In the 2D simulation, we verified the time that takes for the excitation generated from one single shock to propagate through the entire domain (activation time) follows the same power law as the function of electric field strength as experiments. The defibrillation success rate grows as electric field strength increases. And the field strength to reach a success rate of 90% increases as the number of heterogeneities decrease. In the 3D simulation, we observed both successful and unsuccessful LEAP results when the electric field strength and time interval between shocks are varied. The electric field between one point electrode and one surface electrode (plane/concave/convex) can be approximated using image charge methods.

Conclusion

We can achieve real-time simulation on 2D and 3D domain using WebGL to reproduce important characteristics in defibrillation experiments such as activation time and defibrillation success rate. Parameters such as electrode shapes can be modified to improve LEAP performance.



Success Rate
E (V/cm)