Modeling of Human Tissue Damage and Cellular Injury in Electric Shock

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Electrical trauma can result from direct contact with a variety of electricity sources, such as exposed parts of electrical appliances or wiring, high-voltage power lines and lightning. While some electrical shocks may result in minor burns, there still may be serious internal damage, which can produce a complex pattern of injury and clinical manifestations. High-voltage electrical trauma produces some of the most devastating physical injuries. A typical high-voltage electric shock cause massive damages in skeletal muscles, blood vessel and peripheral nerves that can lead to repeated removal of the injured tissues, extensive rehabilitation and limb amputation rates as high as 75%. Due to the variability of electrical shock scenarios, it is almost impossible to precisely diagnose the patient's tissue injury at the time of admission. Therefore, a computer-aided electric shock simulation will provide important insight into the tissue damages and improve the clinical management for electrical trauma.

Tissue injury mechanisms due to electric shock include Joule heating and cell membrane electroporation. We describe a worst-case hand-to-hand high-voltage electrical trauma model that takes both mechanisms into account. Electric field and Joule heating along the tissues in the human upper limb are presented by solving Laplace and Pennes' bioheat equations in a 3-D mesh. Our simulation shows a 7.2k-Volt electric shock with duration of 1-second can cause severe muscle damage in distal forearm. We also evaluated several post-shock treatment methods and found that ice cooling applied immediately post shock reduces the chance of tissue damage by more than 70%. The analysis of electric shock provides insight into the mechanisms of tissue damage and guidance to the development of protection gear and treatment of electric trauma.

Technical challenges and approaches

The model is built upon a 1-mm-resolution human upper extremity MRI image and implemented with thermal and electrical properties of various tissues. We use Beagle to calculate the electric field and temperature distribution of 2.5 million elements over more than 7000 time steps by solving multiple electromagnetic and bioheat equations. The simulation also shows the kinetics of tissue damage caused by plasma membrane electroporation and Joule heating from the shock phase to one hour post shock.
Conclusion

- We presented an electrical shock trauma model (including both electroporation and Joule heating) for worst-case hand-to-hand or hand-to-feet scenarios on 3-d human upper limb mesh

- For a 7.2kV 60-Hz AC shock with 1-second duration, electroporation is the dominant mechanism for muscle damage in shock phase whereas thermal injury dominates the post-shock phase.

- Ice cooling, if applied immediately, is effective in reducing tissue injury

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