On the Modeling of the Effects of Electrically Induced Trauma on Muscle Tissue

Carlos J. Cela*[(1)], Raphael C. Lee [(2)], and Gianluca Lazzi[(1)]
(1) NC State University, Raleigh, NC, USA
(2) University of Chicago, Chicago, IL, USA

It has been long known that the flow of large electric current through living tissue can cause trauma. The process that can lead to tissue damage is complex. However, it is generally accepted that, besides the thermal injuries caused by Joule heating, cellular membrane electroporation and electroconformal denaturation of macromolecules including proteins (i.e. protein unfolding) are tissue-damage mechanisms.

Multiple causes for permanent damage in tissue have been identified. Supra-physiological transmembrane potential can cause electroconformational changes in the membrane's protein, affecting functioning of ion channels and ion pumps. Moreover, since aminoacids (the constituent blocks of proteins) have an electric dipolar moment, a strong electric field can cause reorientation of the macromolecules, and potentially permanent damage. Thermal injury affects all tissues, and in muscle is related to protein denaturation.

Effects of electric shock are frequency dependent. While the cellular wall shields the cytoplasmic fluid from lower frequency components of the electrical current, at high frequencies the cell membrane is no longer an effective barrier to the passage of electrical current. Cell size, cell geometry, and solid-volume ratio also affect the outcome of applying supraphysiological electrical stimulation.

In this work, numerical electromagnetic simulation of the exposure to 60Hz electric current through muscle tissue was performed using a variant of the Admittance Method and realistic 3D human models from the Visible Human project.

The resulting electromagnetic fields were used in conjunction with cell geometry, cell size, and time of exposure to determine potential zones where injury due to electroporation, protein electroconformational denaturation, and Joule heating thermal injury are likely to occur.