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NUMERICAL ANALYSIS OF SINGLE AND MULTI-FREQUENCY CURRENT WAVEFORMS AND THE EFFECT OF OPEN-IRRIGATION COOLING DURING BIPOLAR ELECTROSURGERY

Elzbieta Ewertowska(1), Vincent J. Casey(1), Micheal Burke(2), Kenneth O'Mahony(2), Laoise M. McNamara(1)
(1)Biomedical Engineering, National University of Ireland, Galway;
Centre for Research in Medical Devices (CÚRAM), National University of Ireland, Galway
(2)Stryker, Instruments Innovation Centre, Carrigtwohill, Cork, Ireland
elzbieta.ewertowska@nuigalway.ie, vincent.casey@nuigalway.ie, micheal.burke@stryker.com, kenneth.omahony@stryker.com, laoise.mcnamara@nuigalway.ie

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Summary: Bipolar coagulation is widely used in minimally invasive electrosurgery for neurosurgical hemostasis or tissue removal. The technique makes use of radiofrequency energy delivered in a form of a modulated intermittent current waveform to biological tissue interposed between two closely spaced bipolar forceps. The system offers advantages over monopolar electrosurgery in providing a more localized and precise tissue coagulation and a lower risk of thermal damage into the neighbouring organs. However, tissue adhesion and char formation are the main drawbacks during the procedure, which lead to tissue shearing during electrode removal and delayed tissue healing in regions where excessive carbonization arises. Current waveform and power mode are the main parameters by which heat rate can be controlled during electrosurgical coagulation. Moreover, irrigation-coupled systems have been designed to reduce the temperature response by infusing a low flow cooling fluid to the target tissue [1]. Yet, the coolant can absorb the heat and disperse uncontrollably in tissue, and the appearance of abrupt steam bursts produced in the form of audible pops may additionally displace hot fluid away from the treatment site. Previous studies have developed computer models to investigate the processes involved in heat dissipation in tissue [2][3]. However, little research has been done on tissue thermal response electrosurgery associated with multifrequency waveforms. To the best of our knowledge no computer model has considered an open irrigated cooling system for bipolar coagulation. In this study, 3D FEM models have been built to investigate and better comprehend tissue thermal and electrical response for current waveform modulation, power setting and cooling system involved in bipolar electrosurgical coagulation. Three-dimensional finite element models were developed in COMSOL Multiphysics Software. The problem was formulated as a coupled electrical-thermal analysis accounting for Joule resistive heating and heat convection. The electric and temperature fields were governed by the Laplace equation and the modified bioheat equation, respectively, and temperature dependent tissue properties were considered. The model was informed by the electrical data acquired from an experimental study that was conducted using ideal load (25-1000 Ω) and ex vivo soft tissue samples to characterize current waveforms and frequency spectra (300 kHz - 8 MHz). Bipolar coagulation on soft tissue was carried out at two clinically relevant power settings (7 W and 35 W). Surface temperatures were analysed using real-time infrared thermography and used to validate the computational models. The validated models were applied to investigate modulated input current for a varying number of frequency components and the thermal effect of open irrigation cooling system. This study demonstrated a computational approach to predict thermal damage evolution in tissue under bipolar coagulation with single and multi-frequency waveforms. The results were supported with the experimental data for characterization of the input bipolar 'coag' signal and surface spatial and temporal distributions of temperature. These results revealed how cooling reduced tissue temperatures during bipolar electrosurgery and offer a useful way for the prediction and optimization of bipolar treatments of soft tissue.

References

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[2]Karaki et al., 2019.
[3]Dodde et al., 2008.