Bipolar Radiofrequency Ablation of the Brain Using a Virtual Patient Population

Erica E. Neumann[1,2], Jorge A. Gonzalez-Martinez[3], Ahmet Erdemir[1,2]
[1]Department of Biomedical Engineering, Lerner Research Institute, Cleveland Clinic, Cleveland, OH
[2]Computational Biomodeling (CoBi) Core, Lerner Research Institute, Cleveland Clinic, Cleveland, OH
[3]Epilepsy Center, Neurological Institute, Cleveland Clinic, Cleveland, OH

Introduction: Radiofrequency (RF) ablation is an emerging treatment to laser ablation or resective surgery in medically refractory epilepsy. Treatment using RF ablation is performed at bedside after localization of the epileptic area using stereoelectroencephalography (SEEG), eliminating an additional surgery on the patient. Conventional SEEG electrodes have been used to perform ablations outside the United States [1-4]. However, there is no way to measure temperature during the procedure, therefore making it difficult to assess the ablation volume. Lesion size is dependent on the thermal and electrical properties of the brain, including thermal conductivity, specific heat, electrical conductivity, and blood perfusion. Patient-to-patient variation in these parameters will likely contribute to variations in lesion shape and size. Probabilistic analysis, leveraging computational modeling, provides an opportunity to develop a virtual patient population that reflects the variation of patient parameters. This in silico population can then be used to evaluate the expected outcome of the RF ablation procedure. The goal of this study is to determine the distribution of lesion shape and size during bipolar RF ablation in the brain in a virtual patient population.

Materials and Methods: A two-dimensional axi-symmetric finite element model, incorporating thermo-electric coupling was developed. A simplified SEEG electrode was modeled with two platinum-iridium contacts to accommodate for bipolar ablation, while the remaining length was modeled as plastic material. Material properties of the brain tissue were assigned from literature [5-6]. Latin hypercube sampling was used to select thermal conductivity (tissue and perfusion), electrical conductivity, and heat capacity parameters for probabilistic analysis (n=160), while the remaining material properties were held constant. Ablation was performed for 30 minutes or until tissue temperature reached 100°C, where RF power was modeled using a voltage differential of 20V between two adjacent contacts of the electrode. Lesion length, width, area, and volume, as defined by the 60°C isotherm, were used as response variables.

Results and Discussion: Sample statistics for each response function are shown in Table 1. The variation in width is slightly lower than the variation in length, which is dependent on the contact spacing. In addition, 11 samples (6.9%) did not reach a tissue temperature of 60°C, indicating that a lesion was not formed with the corresponding parameters. In this study, only one voltage curve was tested, i.e. 20V. However, the in silico population used in this study may also be used to test other RF control parameters or power levels in order to reach target size and shape. Model validation will be performed using in vitro and in vivo models. Nonetheless, predicted lesion sizes are within reported literature values [1,3].

Table 1. Summary of response variable statistics (mean with 95% confidence interval).

	Length (mm)	**Width (mm)**	**Area (mm^2)**	**Volume (mm^3)**
Mean [95% CI]	6.73 [6.37, 7.10]	4.87 [4.58, 5.15]	29.02 [26.83, 31.22]	83.11 [75.19, 91.03]

Translational Impact: Development of an in silico patient population through probabilistic analysis provides initial success rates or risk factors without the need for large clinical trials in patients. Further, these methods can be used to refine the design and delivery of RF energy to optimize patient outcomes to confirm the desired lesion shape, size and success rates.

Disclosure Statement: The authors do not have any conflicts of interest to disclose.

Acknowledgements: This study was supported by the Cleveland Clinic Neurological Institute Innovation Fund.

References: [1] Guenot, M. et al. Epilepsia (2004) 45: 1368-1374. [2] Catenoix, H. et al. Epilepsy Res. (2018) 142: 117-120. [3] Cossu, M. et al. Epilepsia (2017) 58 Suppl 1: 66-72. [4] Bourdillon, P. et al. Epilepsia (2017) 58: 85-93. [5] Hasgall, PA. et al. https://itis.swiss/virtual-population/tissue-properties/overview/ (2018). [6] Johansson, JD. et al. Med Bio Eng Comput (2006) 44:757-766.