



## Recent Progress on Design Optimization of Concentric Ring Electrodes Based on Negligible and Finite Dimensions Models

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Concentric ring electrodes (CREs) are noninvasive and wearable sensors for electrophysiological measurement capable of estimating the surface Laplacian (second spatial derivative of surface potential) at each electrode which constitutes their primary biomedical significance. Therefore, optimization of CRE design is an important problem since its criterion is maximization of the Laplacian estimation accuracy. Two CRE models that are currently used for such optimization are the negligible dimensions model (NDM) and the finite dimensions model (FDM). While FDM allows comprehensive optimization where all of the electrode parameters including the radius of the central disc and individual widths of concentric rings (that are considered negligible in simplistic NDM) are optimized simultaneously, it also increases the number of decision variables making the optimization problem more complex. This abstract reports on the recent progress based on both NDM and FDM based optimization.

For the NDM based inter-ring distances optimization, the optimization problem has been solved for pentapolar (4 concentric rings) and sextopolar (5 rings) CRE configurations using a wide range of truncation error percentiles ranging from 1<sup>st</sup> to 25<sup>th</sup>. For example, for the 5<sup>th</sup> percentile, optimal range of values of  $\alpha$ ,  $\beta$  and  $\gamma$  for the pentapolar CRE configuration with middle rings radii equal to  $\alpha r$ ,  $\beta r$  and  $\gamma r$  and outer ring radius of  $r$  such that  $0 < \alpha < \beta < \gamma < 1$  is determined by inequality  $\alpha\beta\gamma \leq 0.213$ . Respective optimal range of values of  $\alpha$ ,  $\beta$ ,  $\gamma$  and  $\delta$  for the sextopolar CRE configuration with an additional middle ring of radius  $\delta r$  such that  $0 < \alpha < \beta < \gamma < \delta < 1$  is determined by inequality  $\alpha\beta\gamma\delta \leq 0.204$ . Obtained results also confirmed consistency between the optimal ranges for all the CRE configurations with up to 5 rings that may allow estimation of optimal ranges for CRE configurations with 6 rings or more at which point optimization problem becomes prohibitively computationally intensive to solve directly.

For the comprehensive FDM based optimization, general principles defining optimal CRE designs have been derived and illustrated on tripolar (2 rings) CRE configuration. For tripolar CREs, the optimal configuration was directly compared to previously proposed and FDM based linearly increasing inter-ring distances and constant inter-ring distances tripolar CRE configurations of the same size. Obtained results suggest that previously proposed configurations correspond to an almost two-fold and more than three-fold increases in Laplacian estimation error respectively compared to the optimal tripolar CRE configuration. Moreover, these analytic results have been confirmed using finite element method modeling adapted from NDM to FDM for the first time to compare the same three tripolar CRE configurations. Finally, finite element method modeling results suggest that optimal tripolar CRE configuration may also offer improved sensitivity and spatial resolution.

Clinical relevance of these NDM and FDM based results is that they may inform future CRE designs. Especially so, for CRE configurations with large numbers of concentric rings which is crucial since accuracy of surface Laplacian estimation has been previously shown to increase with an increase in the number of rings.