Comparing optimal tripolar concentric ring electrode to bipolar and tripolar commercial configurations using finite element method modeling

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Introduction

Concentric ring electrodes (CREs) are showing promise in noninvasive electrophysiological measurement but electrode design criteria are rarely detailed and justified for existing commercial products. Because of that, direct comparisons of proposed electrode designs to commercially available configurations are needed. This poster reports on the recent progress made in comparing the optimal tripolar CRE maximizing the accuracy of the surface Laplacian (second spatial derivative of surface potential) estimation at each electrode to commercial products including bipolar CoDe® electrodes manufactured by Spes Medica [1] and tripolar t-Lead electrodes manufactured by CREmedical [2]. The comparison was drawn using realistic finite dimensions models of the electrodes via finite element method modeling. Obtained results included relative and normalized maximum errors of Laplacian estimation.

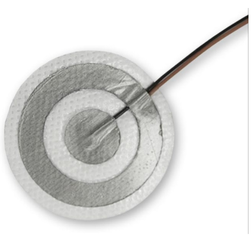

Figure 1. CODE401526 electrode from Spes Medica

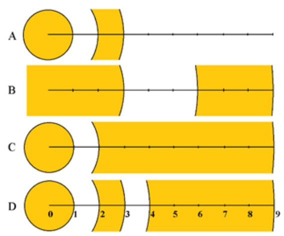

Figure 2. Finite dimensions models for four CRE configurations

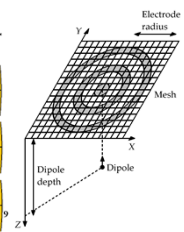

Figure 3. Finite element method model

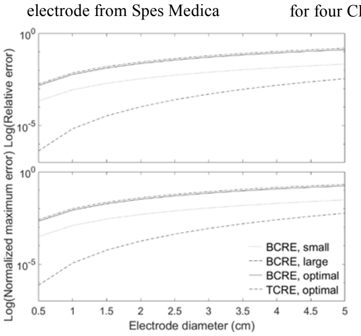

Figure 4. Spes Medica results on semi-log scale

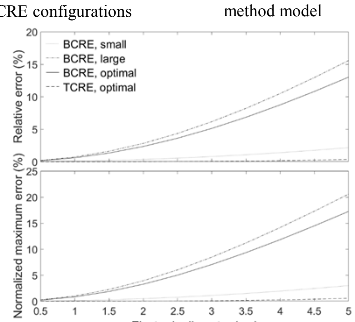

Figure 5. Spes Medica results on linear scale

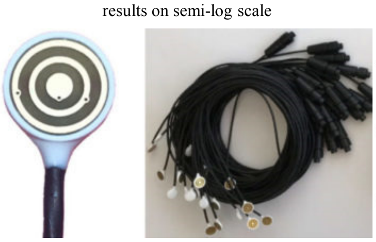

Figure 6. t-Lead electrodes from CREmedical

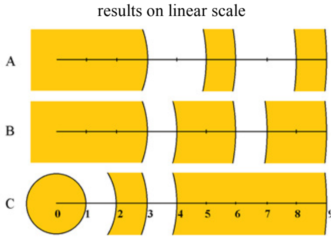

Figure 7. Finite dimensions models for three CRE configurations

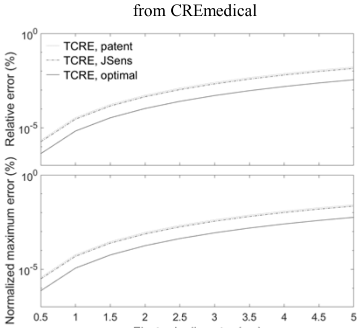

Figure 8. CREmedical results on semi-log scale

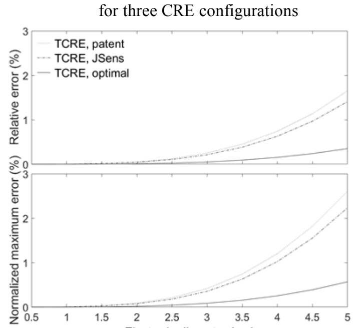

Figure 9. CREmedical results on linear scale

Methods and Results

For bipolar CoDe® electrodes (Fig. 1), novel optimal bipolar CRE configuration (Fig. 2, C) was proposed and included in comparison along with the previously proposed tripolar one (Fig. 2, D). They were compared to bipolar configuration of the same size with dimensions corresponding to CoDe® electrodes (Fig. 2, B) as well as to its scaled version of a different size (Fig. 2, A). Specifically, optimal tripolar configuration was compared to a bipolar configuration consisting out of its central disc and middle ring only (Fig. 2, A versus D). Comparison was drawn using a finite element method model (Fig. 3): evenly spaced mesh corresponding to roughly 20 x 20 cm was located in the first quadrant of the *X-Y* plane over a dipole projected to the center of the mesh and oriented towards the positive direction of the *Z* axis; at each point of the mesh, the electric potential was generated by a unit charge dipole at 5 cm depth; the analytical Laplacian was computed and compared with Laplacian estimates for each CRE configuration. Compared to the optimal tripolar CRE configuration, commercially available CoDe® electrode of the same size corresponded to a median increase in Laplacian estimation errors of 120-146 times while its counterpart one third of its size corresponds to an increase of 15-18 times (Figs. 4, 5) [1]. Compared to the optimal bipolar configuration, commercially available CoDe® electrode of the same size corresponded to a median increase in Laplacian estimation errors of 1.2 times (Figs. 4, 5) [1].

For tripolar t-Lead electrodes (Fig. 6), the use of finite dimensions model of CRE was two-fold. First, it was used to optimize the surface Laplacian estimate coefficients for tripolar electrode configuration with dimensions approximating t-Lead electrodes. Two differential signals representing differences between potentials on the middle ring and on the central disc as well as on the outer ring and on the central disc are combined linearly into the Laplacian estimate with aforementioned coefficients representing the weights of differential signals. Second, it was used to directly compare said tripolar configuration (Fig. 7, A and B) to the optimal tripolar CRE configuration of the same size (Fig. 7, C) . Obtained results suggested that optimal coefficients for Laplacian estimate based on the approximation of the t-Lead dimensions to be (6, -1) as opposed to (16, -1) widely used with this electrode in the past [2]. Moreover, compared to the optimal tripolar CRE configuration, approximation of the commercially available t-Lead electrode of the same size corresponded to a median increase in Laplacian estimation errors of over 4 times (Figs. 8, 9) [2].

Discussion

These results are consistent with prior results based on both the simplistic negligible and the realistic finite dimensions model of the CRE but further investigation on real life phantom and human data via physical CRE prototypes is needed for conclusive proof. The clinical relevance of these results is that quantifying the advantage of optimal over commercially available CRE configurations could provide an insight to inform future electrode designs for real-life applications not limited to the ones that already rely on commercially available CREs.

References

1. Makeyev O., Ye-Lin Y., Prats-Boluda G., Garcia-Casado J., Comparing optimal and commercially available bipolar and tripolar concentric ring electrode configurations using finite element method modeling based on their finite dimensions models, IEEE Sensors Applications Symposium, Sundsvall, Sweden, August 1-3, 2022. https://doi.org/10.1109/SAS54819.2022.9881246

2. Makeyev O., Ye-Lin Y., Prats-Boluda G., Garcia-Casado J., Optimizing Laplacian estimation for the finite dimensions model of a commercial tripolar concentric ring electrode and comparing it to the optimal electrode configuration via finite element method modeling, 9th International Electronic Conference on Sensors and Application, November 1-15, 2022. https://sciforum.net/paper/view/13324

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