Current Versus Optimal Laplacian Estimates For t-Lead Concentric Ring Electrodes Via Finite Element Method Modeling

Alana Benally[1], Oleksandr Makeyev[1], Yiyao Ye-Lin[2], Gema Prats-Boluda[2], Javier Garcia-Casado[2]

[1]*Diné College, Tsaile, AZ;* [2]*Universitat Politècnica de València, Valencia, Spain*

Introduction

t-Lead (Fig. 1) is a commercial tripolar concentric ring electrode (TCRE; CREmedical, Kingston, RI), specifically designed for noninvasive electrophysiological measurement applications, including studies involving human subjects. Utilizing the ability of concentric ring electrodes to directly estimate the second spatial derivative (Laplacian) of surface potential at each individual electrode by linearly combining differential voltages recorded between the central disc and the rings with specific coefficients used as weights makes them of significant importance in biomedicine. Our recent research showed that optimal coefficients (6,-1) maximizing the accuracy of Laplacian estimation for TCRE with dimensions similar to those of the t-Lead are different from the currently used coefficients (16,-1) [1]. This study assesses the difference between optimal and current coefficients via finite element method modeling. This is important since significant difference in Laplacian estimate signal may affect its diagnostic value.

Methods

Finite element method modeling was used to compare the performance of two realistic finite dimensions models approximating the dimensions of the commercially available t-Lead electrodes (Fig. 2A and 2B) determined in [1]. First set of dimensions was patented in [2]. Second set of dimensions was published in [3]. Both sets of dimensions were scaled to the size of the optimal TCRE configuration from [4] with the outer radius of the outer ring subdivided into 9 equal intervals. To derive the suboptimal coefficients from them, additional electrode configuration was considered with a ratio of median radii of 1 to 2 (Fig. 2C). Since current coefficients (16, -1) were originally derived for t-Lead using simplistic negligible dimensions model of an electrode with the same ratio, a modified version of these coefficients (13.8, -1) was derived using finite dimensions model from Fig. 2C to be used as suboptimal coefficients (23/60, -1/36) for configurations approximating t-Lead from Figs. 2A and 2B. Optimal Laplacian estimate coefficients for Fig. 2A (17/63, -1/21) and Fig. 2B (51938/159159, -1202/22737) were adopted from [1]. Second set of suboptimal coefficients was derived from the optimal set by scaling the first coefficient by 16/6 followed by scaling the resulting estimate by 6/16 to avoid a substantial increase in amplitude. Finite element method model was adopted from [1, 4]. Errors of Laplacian estimation corresponding to the optimal and two suboptimal estimates for finite dimensions models from Figs. 2A and 2B served as primary outcomes for comparison.

Figure 1. t-Lead electrodes from CREmedical (https://cremedical.com/product-2-2/).

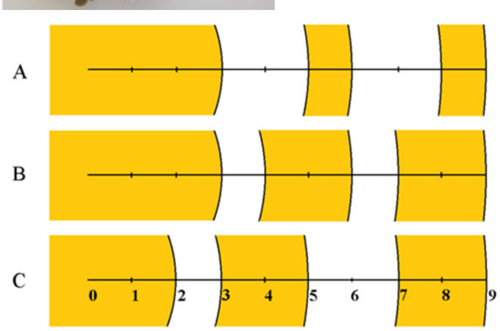

Figure 2. Three finite dimensions models corresponding to: two approximations of t-Lead dimensions (panels A and B) and TCRE configuration with one to two ratio of median ring radii (panel C).

Results

Obtained finite element method modeling results (Fig. 3) indicate median ratio of normalized relative errors corresponding to suboptimal over optimal coefficients for two finite dimensions models approximating t-Lead electrodes to range between 479 and 644 times. Respective ratio of maximum errors ranges from 278 to 375 times.

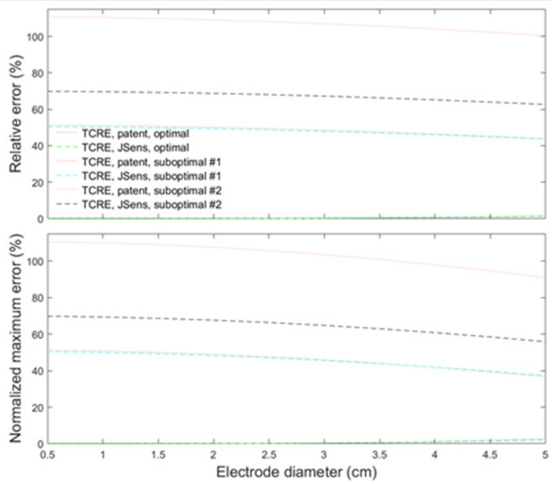

Figure 3. Relative (top panel) and normalized maximum (bottom panel) errors of surface Laplacian estimation corresponding to two tripolar concentric ring electrode configurations approximating t-Lead dimensions with three sets of coefficients for each including the optimal and two suboptimal ones respectively.

Discussion

While aforementioned preliminary error ratios suggest a significant difference in Laplacian estimation accuracy further investigation is needed to address the following. First, at this point of time difference in amplitudes of resulting Laplacian estimate signals corresponding to optimal and suboptimal coefficients has not been studied and difference in amplitudes may affect respective estimation errors. Addressing this is the first step of envisioned future work. Second, other approaches of determining suboptimal coefficients may result in closer fit to currently used (16, -1). Finally, any modeling based results need to be validated on real life phantom or human data using physical electrode prototypes.

References

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