Optimized interferential electric fields for noninvasive deep focal brain stimulation

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Synopsis: Interferential stimulation (IFS) has generated considerable interest recently because of its potential to achieve focal stimulation in deep brain areas. In principle one can deliver currents with more than the two pairs of electrodes conventionally used with IFS. However, at present there is no systematic approach to optimize the location and currents of the multiple electrodes. We formulate a rigorous optimization criterion of IFS to achieve maximal modulation (max-intensity) or most focal stimulation (max-focality). We solved the IFS optimization either analytically (for max-intensity) or numerically (for max-focality) and show that optimized IFS can achieve more focal stimulation compared to conventional stimulation without interferential fields, both at cortical surface and in deep brain.

Background: IFS carries the promise to achieve focal stimulation inside the brain with currents applied transcranially [1]. Currently IFS adjust the locations of 2 pairs of high-definition (HD) electrodes by trying different locations in computer simulations [1]. There are some concerns that the resulting intensity distributions are no more focal or "deep" than existing multi-electrode methods [2]. However, electrode location and currents have never been systematically optimized of IFS.

Methods: Starting from the exact mathematical description of IFS in [2], we show analytically that to stimulate a specific location in the brain with maximal intensity of the electric field, one simply needs to "fuse" the 2 pairs of HD electrodes proposed in [1] to a single pair of electrodes at locations determined by the conventional optimized HD-TES [3]. In addition, we present the exact mathematical formulation of the IFS optimization to achieve maximally focal stimulation and solve it numerically. The achieved focality at both cortical surface and deep brain location are compared to that from conventional optimized HD-TES.

Results: The analytic results indicate that maximal modulation intensity is achieved with just two electrodes, which can be selected using a simple rule without the need for numeric optimization. This rule is confirmed with numerical optimization on a realistic head model. To achieve maximally focal stimulation with IFS a numerical optimization can finds electrode configurations that achieve 1.1 cm and 2.3 cm focal spots for a location at cortical surface and a location in deep brain, respectively, more focal than that achieved from optimized conventional HD-TES (2.0 cm at cortical location, 5.3 cm in deep brain).

Discussion: The proposed optimization techniques can be translated to clinical use for noninvasively stimulating deep brain locations with maximally focal electric field.

[1] N. Grossman, D. Bono, N. Dedic, S.B. Kodandaramaiah, A. Rudenko, H.-J. Suk, A.M. Cassara, E. Neufeld, N. Kuster, L.-H. Tsai, et al. Noninvasive deep brain stimulation via temporally interfering electric fields. Cell, 169 (6) (2017), pp. 1029-1041

[2] Yu Huang, Lucas C. Parra, 2018, Can transcranial electric stimulation with multiple electrodes reach deep targets? Brain Stimulation, Volume 12, Issue 1, January–February 2019, Pages 30-40

[3] J.P. Dmochowski, A. Datta, M. Bikson, Y. Su, L.C. Parra, Optimized multi-electrode stimulation increases focality and intensity at target. J Neural Eng, 8 (4) (2011), p. 046011