

Wireless Retinal Stimulation Using Magnetoelectric Nanoparticles: A Novel Approach for Non-Invasive Neurostimulation

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Purpose: Traditional electrode-based neurostimulation methods can be invasive and raise concerns about long-term functionality. In contrast, magnetoelectric nanoparticles (MENPs) offer a non-invasive alternative by creating localized electric fields from external magnetic fields. This study explores the use of MENPs for wireless stimulation in retinal tissue using GCaMP6f mouse, assessing cellular responses to this magnetically induced stimulation. Previous research has shown MENPs' effectiveness in modulating neural activity with high precision, highlighting their potential in treating neurological disorders, along with their biocompatibility and controllability by external magnetic fields.

Methods: Magnetoelectric nanoparticles (MENPs) are core-shell nanostructures composed of CoFe₂O₄ and BaTiO₃, measuring less than 30 nm in size. COMSOL Multiphysics was used to model the magnetoelectric behavior of these MENPs by adjusting their geometric features. The MENPs were introduced into the retinal tissues of GCaMP transgenic mice, which express a genetically encoded calcium indicator. A 100 mT alternating current (AC) magnetic field at a frequency of 50 Hz was applied to activate the nanoparticles, which induced localized electric fields to stimulate the retinal cells. Calcium imaging was conducted to evaluate the cellular responses to this stimulation. Control groups included untreated retinal tissues and tissues treated with MENPs but exposed to lower magnetic field intensities. Changes in brightness intensity of the neurons were analyzed to assess their responses correlated with the stimulation.

Results: Simulations indicate that the electric field generated by MENPs exceeds 100 V/cm, surpassing the threshold required to stimulate the retina. In retinal tissues treated with MENPs, changes in calcium fluorescence ($\Delta F/F_0$) exceeding 5% were observed following magnetic stimulation, suggesting a potential response to wireless stimulation. In contrast, no significant changes in fluorescent intensity were detected in control groups that did not receive nanoparticles or exposed to lower magnetic field exposure. These findings highlight that MENPs may influence neural activity through the generation of localized electric fields.

Conclusions: Initial findings suggest that MENPs may allow for wireless stimulation of retinal neurons, but further optimization and quantitative analysis are necessary to confirm efficacy. Improved delivery methods and design adjustments for stronger magnetic fields within temperature limits are essential. The ultimate goal is to activate retinal neurons effectively.