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Physical and Biological Implications of Capacitive Coupling for Electric Pulse Treatments

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Conventional biomedical applications of electric pulse (EP) stimulation utilize conductive coupling, where the electrodes directly contact the biological sample; however, this may contaminate the sample due to ion release from the electrodes. One such application involves activating platelets ex-vivo to create gels for wound treatment without traditional biochemical activators that may induce adverse side effects [1]. The proposed mechanism involves EP induced membrane permeabilization facilitating calcium transport into the platelets to induce activation [2]. Recent platelet activation studies have emulated capacitive coupling, a non-contact method of electrical stimulation, by placing a capacitor between the pulse generator and sample. While the calculated membrane voltage is far below the typical electroporation threshold, experiments show that capacitive coupling induces growth factor release levels comparable to conductive coupling. It is interesting that treating samples with low intensity, bipolar EPs separated by hundreds of nanoseconds by capacitive coupling was effective since applying higher intensity bipolar nanosecond EPs using conductive coupling actually induced less cell death and ion transport into the cell than equivalent high intensity monopolar EPs [3]. The presence of significant biological effects for lower intensity bipolar pulses may suggest that non-electrical mechanisms, such as shock waves, cancel biological effects at higher intensities. We further assess calcium dynamics by coupling the asymptotic Smoluchowski equation for pore formation to the Nernst-Planck equation for ion motion. The implications of these results for EP-induced mechanisms and applications will be discussed.

[1] V. B. Neculaes et al., "Ex vivo platelet activation with extended duration pulse electric fields for autologous platelet gel applications,"EWMA Journal, vol. 15, no. 1, pp. 15-19, 2015.

[2] J. Zhang et al., "Nanosecond pulse electric field (nanopulse): A novel non-ligand agonist for platelet activation,"Arch. Biochem. Biohpys., vol. 471, pp. 240-248, 2008.

[3] A. G. Pakhomov et al., "Cancellation of cellular responses to nanoelectroporation by reversing the stimulus polarity,"Cell. Mol. Life Sci., vol. 71, pp. 4431-4441, 2014.

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