Capacitive technologies for highly controlled and personalized electrical stimulation by implantable biomedical systems

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Cosurface electrode architectures are able to deliver personalized electric stimuli to target tissues. As such, this technology holds potential for a variety of innovative biomedical devices. However, to date, no detailed analyses have been conducted to evaluate the impact of stimulator architecture and geometry on stimuli features. This work characterizes, for the first time, the electric stimuli delivered to bone cellular tissues during in vitro experiments, when using three capacitive architectures: striped, interdigitated and circular patterns. Computational models are presented that predict the influence of cell confluence, cosurface architecture, electrodes geometry, gap size between electrodes and power excitation on the stimuli delivered to cellular layers.

The results demonstrate that these stimulators are able to deliver osteoconductive stimuli. Significant differences in stimuli distributions were observed for different stimulator designs and different external excitations. The thickness specification was found to be of utmost importance. Frequency-dependent and region-dependent electric field stimuli are delivered to osteoblastic cells (Fig. 1). Maximum electric stimuli of 0.3 V/mm and 0.7 V/mm was delivered to the cellular tissues using electrodes with 100 μm thick for 14 Hz and 60 kHz, respectively, and 10 V voltage excitation. In vitro experiments using an osteoblastic cell line highlight that cosurface stimulation at a low frequency can enhance osteoconductive responses, with some electrode-specific differences being found (Fig. 2). A major feature of this type of work is that it enables future detailed analyses of stimuli distribution throughout more complex biological structures, such as tissues and organs, towards sophisticated biodevice personalization.

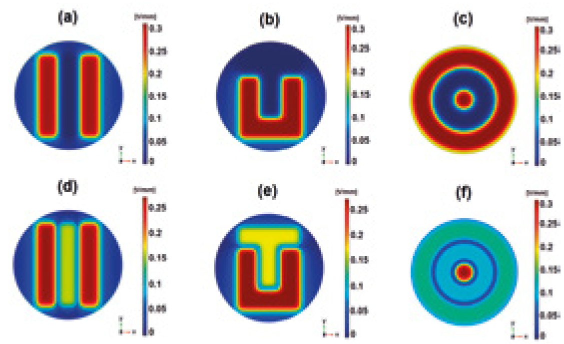

FIGURE 1
Electric field stimuli delivered to MC3T3 osteoblasts for low frequency (a–c) and high frequency (d–f) excitations delivered by: (a,d) a striped pattern; (b,e) a interdigitated pattern; (c,f) a circular pattern.

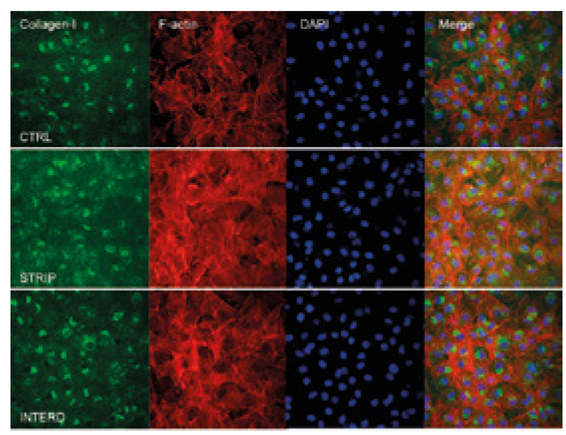

FIGURE 2
Confocal microscopy analysis of MC3T3 osteoblasts cultured for 28 DIV in the absence of stimulus (CTRL) or upon daily stimulation with two electrode patterns (striped [STRIP] and interdigitated [INTERD]). Cells were probed for type-I collagen (green fluorescence), DAPI (blue nuclear staining), and filamentous actin (F-actin, probed with red-labeled phalloidin). The scale bar is 50 μm.