Graphene Foam Bioscaffolds for Modulating Cellular Behavior and Mechanical Properties Under Scaffold-Coupled Electrostimulation

Mone't Sawyer and David Estrada*
Boise State University,1910 University Drive, Bosie, USA
monetalberts@u.boisestate.edu | *daveestrada@boisestate.edu

Electrostimulation (ES) with conductive biomaterials offers a promising strategy to influence cellular behavior and enhance functional tissue regeneration. 3-dimensional (3D) graphene foam (GF) scaffolds, hold immense potential for modulating stem cell differentiation due to their unique electrical, topographical, and chemical properties. Our team has previously shown that 3D GF enables growth of 3D musculoskeletal tissue. [1-3] However, integration of ES protocols during cell culture on 3D GF scaffolds remains limited. This challenge is exacerbated by a lack of techniques to characterize cell morphology on visibly opaque 3D GF. Here, we present an integrated approach that combines multimodal microscopy, advanced manufacturing of ES bioreactors, and dynamic mechanical characterization to investigate 3D GF as an electroactive scaffold. Scaffold-coupled ES was applied to murine chondrogenic progenitor ATDC5 cells using biphasic square wave stimulation (20, 40, and 60 mVpp), leading to a 25% increase in equilibrium modulus and a 65% increase in steady-state energy dissipation at 60 mVpp compared to unstimulated controls (Figure 1). Cell proliferation was significantly enhanced, with 4.68 × 10^3 cells/mm^3 at 60 mVpp, compared to 2.53 × 10^3 and 2.14 × 10^3 cells/mm^3 at 20 mVpp and 40 mVpp, respectively. Our correlative microscopy technique enabled a non-destructive visualization of cellular infiltration into GF's hollow branches, revealing a 2-fold increase in cell volumes and enhanced integration in ES bioreactors compared to standard culture ware, where GF's hydrophobicity limits cell adhesion [4,5]. These findings establish GF as a scalable platform for ES enhanced tissue engineering and highlight our ability to influence mechanical properties and cell proliferation using custom ES bioreactors.

References

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Figures

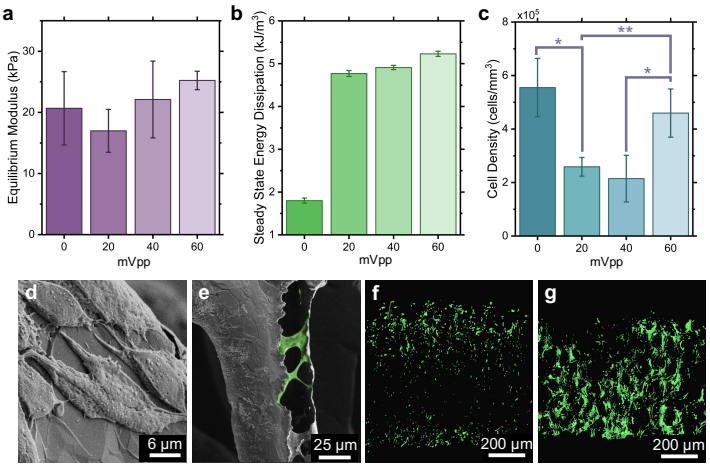

Figure 1: Characterization of GF-cell composites after 7 days of scaffold-coupled ES and 7 days of additional culture. (a) Equilibrium modulus, (b) steady state energy dissipation under cyclic compression, (c) cell density, (d-e) SEM images of cell morphology (d) and cells bridging structural branch cracks (false-colored to green) within GF (e), (f-g) MicroCT of cellular architecture in GF, showing sparse, rounded cells in commercial cultureware (f) versus denser, elongated cells aligning with GF microstructure in custom bioreactors (g).