Graphene oxide, reduced graphene oxide and composite scaffolds for bone tissue engineering with hierarchical pore size distributions via a dual-templating strategy

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Scaffolds for bone tissue engineering (BTE) are three-dimensional (3D) porous matrices that provide the necessary sites for cell adhesion and proliferation, where the architecture plays an important role. Ideally, BTE scaffolds should have an interconnected network of both large (>100 mm) and small pores to facilitate the infiltration of cells and the diffusion of growth factors and nutrients1. Scaffolds for BTE should also enhance osteogenic differentiation to improve bone regeneration. Graphene oxide (GO) and reduced graphene oxide (rGO) can promote osteogenic differentiation of mesenchymal stem cells (MSCs) because they can provide biophysical cues and adsorb biological factors2. However, due to the lack of effective fabrication strategy, it remains a challenge to develop GO and GO composite scaffolds with a hierarchical architecture aiming for BTE. In this study, we developed a dual-templating method that produces GO scaffolds with interconnected hierarchical porosity: upon freezing and drying GO-based high internal phase emulsions, large pores were templated by the oil droplets, and small pores by ice crystals formed in the water phase, whose size can be controlled by the freezing temperature. We also obtained GO emulsions composited with polyacrylic acid (PAA), hydroxyapatite (HA), and elastin from bovine neck ligament. From the emulsions, we obtained GO composite scaffolds with hierarchical architectures. Furthermore, through the thermal reduction of GO scaffolds, we also fabricated rGO scaffolds with different reduction degrees that maintained the mother scaffolds' structure. We studied the formation of emulsions and the structural and chemical properties of scaffolds through optical microscopy, scanning electron microscopy (SEM), synchrotron-based X-ray phase contrast imaging (PCI), X-ray photoelectron spectroscopy, and attenuated total reflectance Fourier transform infrared spectroscopy. We seeded mouse bone marrow MSCs on GO scaffolds and analyzed the cells after 7 days of incubation using SEM and confocal microscopy to study cell morphology, attachment, and infiltration in the scaffolds. The resulting GO scaffolds were excellent substrates for MSC growth and penetration — an unprecedented result since previous fabrication methods did not produce GO scaffolds with suitable pore size for BTE. This method also enabled, for the first time, the synthesis of complex hierarchical architectures in GO, rGO, and GO composite scaffolds, through a single, versatile strategy.

REFERENCES

[1] Karageorgiou V et al, Biomaterials 27 (2005), p. 5474-91
[2] Lee WC et al. Acs Nano 9 (2011), p. 7334-41

FIGURES

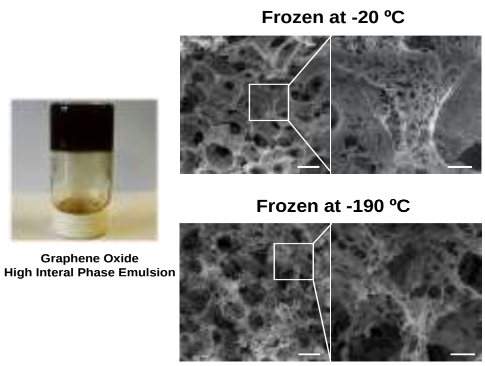

Figure 1: Photo of graphene oxide high internal phase emulsion in a glass vial, SEM images of hierarchical porous scaffolds obtained by emulsion and ice dual-templating frozen at different temperature.