Incorporation of Nano-sized Bioactive Glass Enhances the Mechanical Properties of Electrochemically Aligned Collagen Fibers

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Introduction: Bone disorders are a significant health problem worldwide. Current clinical treatments for bone disorders using autografts and allografts are limited due to concerns such as donor-site morbidity and immunological complications, respectively. Over the past three decades, bone tissue engineering (BTE) has gained considerable interest as an alternative treatment method for bone disorders. BTE mandates the development of a functional scaffold that mimics the native bone extracellular matrix (ECM) niche.[1] To this end, several studies have employed collagen-hydroxyapatite hybrid scaffolds for BTE applications; however, these studies have met with limited success primarily due to the slow bone restoration capability of hydroxyapatite (HA). Bioglass (45S5) has been shown to significantly expedite bone restoration compared to HA suggesting that Bioglass (BG) is more bioactive.[2] While many studies have combined BG and collagen to develop scaffolds for orthopedic applications;[3,4] to the best of our knowledge, the current study is the first attempt to incorporate nano-sized BG (nBG) within an aligned collagen matrix. An electrochemical method was employed to incorporate nBG within highly aligned and dense collagen fibers and hence mimic the compositional and structural aspects of the native bone ECM niche for the development of a functional scaffold for BTE applications.

Materials and Methods: Composite mixtures of dialyzed type I collagen (Collagen Solutions Plc) and nBG (Mo-Sci Corporation; 10% and 60% nBG by weight) were loaded between two electrodes and an electric field of 3V was applied for 30 min. The presence of an electric field triggers the formation of a pH gradient between the electrodes thereby imparting a charge to the collagen molecules (positively charged close to anode and negatively charged close to cathode). Since the electrodes have a similar charge, the molecules repel away from the electrodes and align along the isoelectric point. During the alignment process, the nBG particles entrap within aligned collagen to form nBG incorporated electrochemically aligned collagen (ELAC) fibers. ELAC fibers without nBG were used as control. SEM analysis was performed to confirm the incorporation of nBG within ELAC fibers. Monotonic tensile tests were performed to assess the effect of nBG incorporation on the mechanical properties of ELAC fibers.

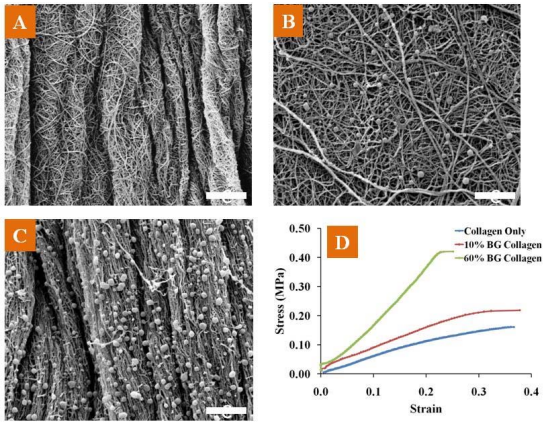

Figure 1: (A-C) SEM images for collagen only (A), 10% BG (B) and 60% BG (C) ELAC fibers. Scale bar = 2 µm. (D) Stress vs. strain curve for mechanical assessment of nBG incorporated ELAC fibers.

Results and Discussion: SEM analysis confirmed that nBG was uniformly incorporated within the ELAC fibers (Fig 1A-C). Tensile test results (Fig. 1D) showed the ultimate tensile strength of ELAC fibers with 60% BG (0.43 MPa) was significantly greater ($p < 0.05$) than ELAC fibers with 10% BG (0.19 MPa) and ELAC fibers with no BG (0.16 MPa). Further, stiffness of ELAC fibers with 60% BG (2.64 MPa) was significantly higher ($p < 0.05$) than ELAC fibers with 10% BG (0.84 MPa) and ELAC fibers with no BG (0.53 MPa). Together, these results suggest that incorporation of nBG significantly enhanced the mechanical properties of ELAC fibers possibly via stronger reinforcement of the collagen fibers.

Conclusions: Overall, incorporation of nBG significantly enhanced the mechanical properties of ELAC fibers. Future studies will focus on assessing the cellular response on nBG incorporated ELAC fibers. The aligned topography of ELAC fibers together with the rapid ionic dissolution of nBG particles can promote osteogenic differentiation, *de novo* matrix formation and mineralization. In conclusion, nBG incorporated ELAC fibers have significant potential to be used for BTE.

References: [1] Amini, A.R., *et al.* Crit Rev Biomed Eng, 2012. [2] Oonishi H, *et al*. Clin Orthop Relat Res, 1997. [3] Marelli B, *et al*. Biomacromolecules, 2010. [4] Sarker B, *et al.* Adv Healthc Mater, 2015.