Osteoblast Cellular Functions on Electron Beam Melting (EBM) Printed 3DTitanium Foam Structures as a Function of Porosity

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Statement of Purpose: The cellular activity, biological response, and consequent integration of scaffold-cell construct in the physiological system are governed by the ability of cells to adhere, proliferate, and biomineralize. In this regard, we combine cellular biology and materials science and engineering to fundamentally elucidate the interplay between cellular activity and interconnected three-dimensional foamed architecture obtained by a novel process of electron beam melting and computational tools. Furthermore, the organization of key proteins, notably, actin, vinculin, and fibronectin, involved in cellular activity and biological functions and relationship with the structure was explored. The interconnected foamed structure with ligaments was favorable to cellular activity that includes cell attachment, proliferation, and differentiation. The primary rationale for favorable modulation of cellular functions is that the foamed structure provided a channel for migration and communication between cells leading to highly mineralized extracellular matrix (ECM) by the differentiating osteoblasts. The filopodial interaction amongst cells on the ligaments was a governing factor in the secretion of ECM, with consequent influence on maturation and mineralization.

Results: The ability of cells to migrate throughout the interconnected porous structure and form colonies confirmed the natural adaptation of preosteoblasts to the 3D environment. Cells adhered to the ligament with numerous cytoplasmic extensions (Fig 1). The interconnecting porous architecture and the elongated morphology of the cells forming bridge between the pores contributed to the migration of cells and consequently colonization of the entire structure. It is natural to expect that the intercellular filopodial interactions between neighboring cells contributed to the secretion of ECM, leading to maturation and mineralization with progress in proliferation.

Conclusions: Pore diameter and interconnected porous architecture are important and practically relevant determining factors that strongly contribute to bone ingrowth on 3D structures by influencing cell proliferation, differentiation, mineralization, and synthesis of actin, vinculin, and fibronectin. We conclude that the 3D interconnected porous foam-type structure enables mechanical interlocking with the surrounding bone and promotes cell and tissue ingrowth by allowing cells to penetrate into the pores. The favorable biological response of cellular foam structures (with the modulus and pore size varying from ~6-1 GPa and ~700–1500 mm, respectively, in foam), and decrease of mismatch of modulus points to the potential of using 3D printed foam structures for bone healing.

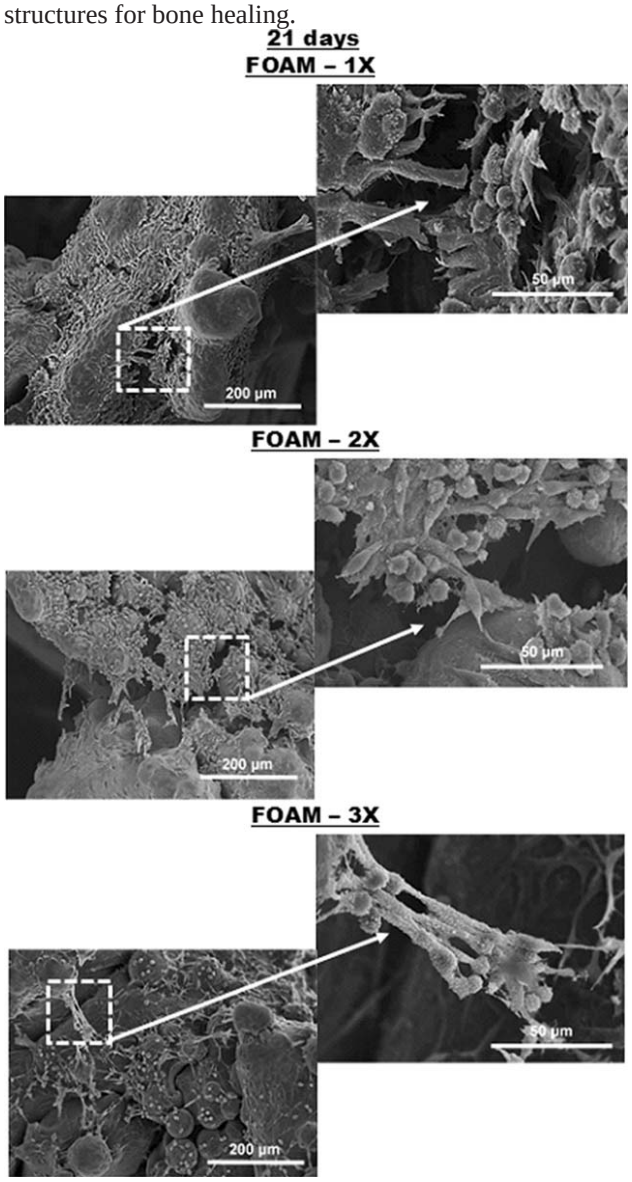

FIGURE 1. Low (left) and high (right) magnification scanning electron micrographs representing cellular ingrowth, interconnectivity of preosteoblasts (bridging the pores), and mineralized nodules on 3D porous Ti alloy foam structure with different porosity (Foam 1X: porosity_76%, Foam 2X: porosity_86%, and Foam 3X: porosity_90%), after 21 day incubation period. High magnification areas are indicated by dotted squares in the low magnification images.