Development of customized patient-specific cranio-maxillofacial scaffolds fabricated by binder-jetting 3D printing of biodegradable Fe-based alloys

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Statement of Purpose: Customized patient-specific care and implant devices are of high demand in providing medical care for trauma and cancer afflicted patients. Precise fit of the bone graft in the defect site is ideal for generating the desired beneficial outcome of cranio-maxillofacial surgeries. Conventional machining and rapid prototyping techniques have been explored for fabricating customized devices [1]. However, 3-dimensional printing (3DP) can generate customized scaffolds rapidly with much ease. Various biomaterials have been used for fabricating the cranio-maxillofacial devices [2, 3]. 3D printing of titanium and stainless steel has been studied for cranio-maxillofacial bone defect models [4]. However, long term use of inert metal implant devices often result in metallosis causing swelling, inflammation, and aseptic fibrosis [5]. We have already developed biodegradable Fe-based alloys for customized patient-specific cranio-maxillofacial scaffolds. Results of the feasibility and in vitro assessment are currently presented in the current abstract.

Methods: P5 planetary milling machine was used to achieve solid solution of pure elemental Fe, Mn, and Me[1] powder in high purity. FeMn, and FeMnMe[1] powder alloys were synthesized, and hence, printed using binder-USA). The surface morphology of sintered 3DP samples were imaged using scanning electron microscopy.3D-printed specimens were sintered and characterized for MTT and Live/dead cell viability assays. Murine pre-osteoblast cell line (MC3T3) was used for the in vitro assessment.

Results: In order to verify the feasibility of fabricating binder-jetting 3D printing technique for this study, CT scan of goat mandible was converted to stereolithography file for mimicking the mandible using the FeMn binary alloy powder (**Figure 1**).

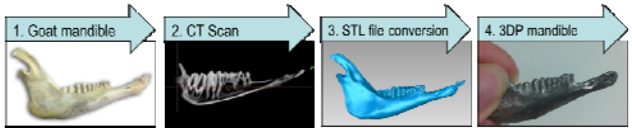

Figure 1: 3D printed goat mandible using CT scan.

The morphology of the 3D printed Fe-based alloy and pure Fe powder exhibited higher porosity for pure Fe due to the finer powder size seen in **Figure 2**. Pure Fe used for synthesis of Fe-based powder alloy was also used as a positive control. 3D printed specimens were examined for in vitro cell viability assays such as MTT and Live/dead assays. **Figure 3** exhibited live and dead cells stained as green and red in the fluorescence images after 1 and 3 day culture of MC3T3 on the surface of the constructs.

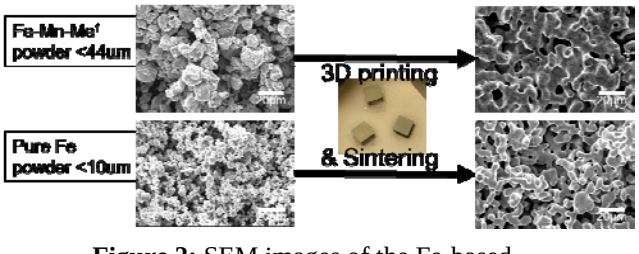

Figure 2: SEM images of the Fe-based powder and sintered products.

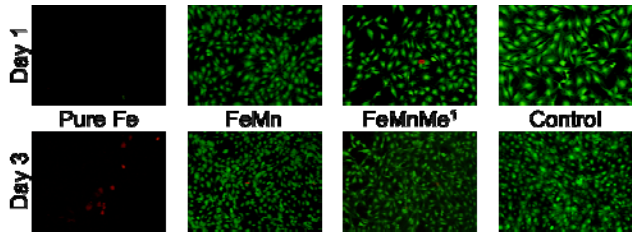

Figure 3: Live/dead cell viability assays on 3D printed specimens.

3D printed FeMn and FeMnMe[1] exhibited live cells comparable to the cell culture plastic control. Indirect MTT assay and the extract medium were prepared in accordance with ISO 10993:5-12. Inductively coupled plasma was used to assess the ionic concentration of the alloying element in the MTT extract (**Table 1**). Much higher Fe concentration was observed in the 3D printed pure Fe compared to Fe-based alloys. This observation was coherent with no live cells found in the fluorescence images of 3D printed pure Fe. Despite the presence of higher Fe ion concentration, the extract media from all 3D printed products, including pure Fe, were observed to be cytocompatible (**Figure 4**).

Figure 4: Indirect MTT cell viability assay on 3D printed products.

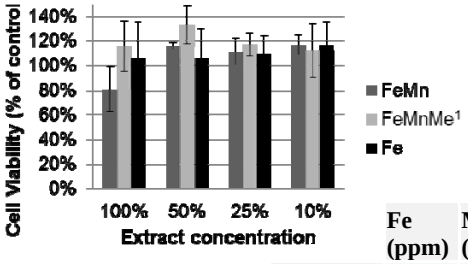

Table 1. Concentration of MTT extract media

	Fe (ppm)	Mn (ppm)	Me[1] (ppm)
Fe	136.1	-	-
FeMn	3.01	4.53	-
FeMnMe[1]	4.43	4.40	29.1

Conclusions: Current work demonstrates the feasibility of using 3D printing of biodegradable Fe-based alloy as potential graft and fixation device for cranio-maxillofacial bone defects. Future work will be focused on fabrication of porous scaffolds for preliminary in vivo study.

References: [1] Eufinger H. J Craniomaxillofac Surg 1995; 23: 175–181. [2] Cooke MN. J. Biomed. Mater. Res. 2003; 64B, 65–69. [3] H. Eufinger. Plast Reconstr Surg, 102 (1998), p. 300. [4] BBC (2012). Transplant jaw made by 3D printer claimed as first. [31 Oct. 2014]. [5] Joshua J. J Bone Joint Surg Am, 1998 ;80(2):268-82.