

Self-Propagating High-Temperature Synthesis (SHS) of Porous Calcium Phosphate (CaP) Scaffolds Substituted with Magnesium or Strontium

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Statement of Purpose: Self-propagating high temperature synthesis (SHS) is an alternative method of producing porous, bioresorbable calcium phosphate (CaP) scaffolds for bone tissue engineering. SHS is a solid-state combustion synthesis (CS) technique that utilizes the energy generated by the exothermic reaction of calcium oxide (CaO) and diphosphorous pentoxide (P₂O₅) to sustain the propagation of a combustion wave through the reactants converting them into CaP products¹. SHS reactions are highly versatile; reaction chemistry can be modified to incorporate divalent cations (Mg or Sr) into the CaP product. CaP scaffolds substituted with <20 weight percent (wt%) Sr have exhibited higher compressive strengths than tricalcium phosphate (TCP) and hydroxyapatite (HA) scaffolds² and the addition of Mg and Sr in CaP scaffolds has shown increased bone formation, bioresorption and cellular activity^{2,3,4}. This research describes a novel technique for production of porous, bioresorbable CaP scaffolds for use as synthetic bone graft materials.

Methods: The CaP SHS reaction system was modified to produce scaffolds substituted with 1, 5 or 7wt% Mg or Sr. Reactant powders were prepared in a desiccated Ar atmosphere due to the reactive nature of P₂O₅, CaO, P₂O₅ (Both Fisher) and magnesium oxide (MgO, Alfa Aesar) or strontium oxide (SrO, Alfa Aesar) were combined in the amounts displayed in Table 1 and mixed for 60s. The reaction for the systems considered includes a TCP phase with Mg or Sr substituted into Ca sites:



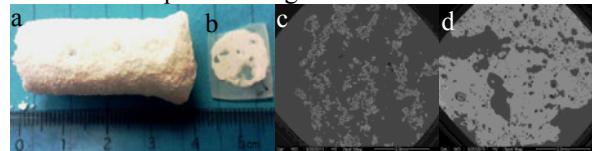
$3\text{CaO} + \text{P}_2\text{O}_5 + x\text{SrO} \rightarrow \text{Ca}_{3-x}\text{Sr}(\text{PO}_4)_2$ where $0 \leq x \leq 1$. Pellets ($d=0.5\text{in}$, $h=1.5\text{in}$, $w=5\text{g}$) were uniaxially cold-pressed (2000psi) with a stainless steel die, placed in a combustion chamber, reacted in an Ar atmosphere and air-cooled to room temperature ($>200^\circ\text{C}/\text{min}$)¹. Reaction times were <15s from initiation to completion¹.

Table 1 Designation	Wt% MgO or SrO (g)	CaO (g)	P ₂ O ₅ (g)	Porosity (%)	Max. Pore Size (μm)	Compressive Strength (psi)
CaP-Mg 1	1	53.70	45.30	66.02	65±7	20.5±13.5
CaP-Mg 5	5	51.53	43.47	64.77	93±27	26.5±2.5
CaP-Mg 7	7	50.44	42.56	65.34	49±7	10.7±0
CaP-Sr 1	1	53.7	45.3	76.86	137±17	54.7±23.4
CaP-Sr 5	5	51.53	43.47	67.60	68±28	36.0±36.8
CaP-Sr 7	7	50.44	42.56	69.45	47±11	12.8±4.8
TCP	-	54.24	45.76	98.91	313±137	32.0±2.8
HA	-	56.84	43.16	71.07	198±110	30.3±3.6

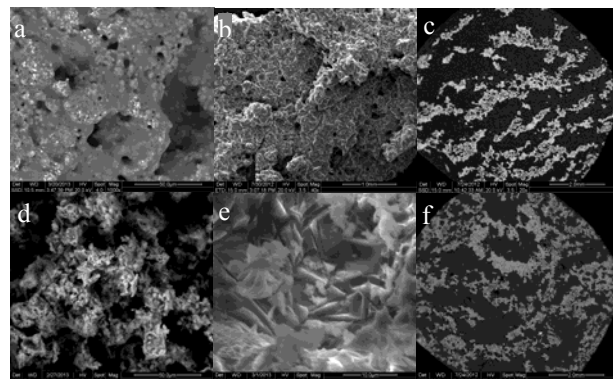
Results: Porous 5g TCP, HA and CaP scaffolds substituted with specific wt% of Mg or Sr were successfully produced with SHS (Figure 1).

Scanning electron micrographs (SEMs) of the TCP control and all CaP-Mg samples are similar and display spherical grains dispersed in a matrix with no distinguishable crystal structure (Figures 2a-b). The HA control and CaP-Sr samples have similar angular, plate-like microstructures (Figures 2a-b). Backscatter SEMs of

CaP-Mg 5 and CaP-Sr 5 (Figures 2c,f) exhibit smaller maximum pore sizes than the controls (Figures 1c,d). Additionally, maximum pore size decreases as Mg/Sr concentration increases (Table 1). Porosity for all substituted samples except CaP-Sr 1 (Table 1) is less than the HA and TCP controls. As MgO/SrO concentration increases SHS reaction temperature decreases, resulting in less off-gas production subsequently generating smaller, more uniform pores throughout the scaffold.



Figures 1a-d. a. Synthesized TCP scaffold b. Embedded and sectioned TCP scaffold. Micrographs (25x) of sectioned scaffolds c. TCP d. HA.



Figures 2a-f. SEM micrographs of a. TCP particle b. CaP-Mg 5 particle c. CaP-Mg 5 section d. HA particle e. CaP-Sr 5 particle f. CaP-Sr 5 section.

Compression data for all scaffolds is presented in Table 2. Average compressive strength (CS) decreased with increasing wt% Mg or Sr. CS for the HA and TCP controls were similar. CaP-Sr 1 and CaP-Sr 5 had the highest average CS but also the largest standard deviation between measurements.

Conclusions: SHS is a viable alternative for production of porous CaP scaffolds substituted with Mg or Sr. As Mg and Sr content increased maximum pore size and compressive strength decreased. Scaffolds substituted with Sr and Mg had lower porosities (except CaP-Sr 1) and smaller maximum pore sizes than the TCP and HA controls which could affect bioresorption and cellular activity.

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