# PHASE CHANGES AND DEGRADATION OF CALCIUM POLYPHOSPHATE

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## INTRODUCTION

Porous calcium polyphosphate (CPP) implants are proposed as biodegradable load-bearing bone substitutes. Such implants should provide required mechanical strength, allow uninhibited bone ingrowth throughout the interconnected pores and should degrade at an appropriate rate. Both mechanical strength and degradation rate are determined by the macrostructure, microstructure and phases as well as molecular weight of CPP. Three phases of CPP, (α, β and γ), are commonly reported[1,2,3]. Attempts to use XRD to analyze the crystal structure of CPP are difficult as all of these crystal structures are monoclinic with small differences in lattice parameters.

Recently, we adopted Solid-State Nuclear Magnetic Resonance (SS NMR) to analyze CPP in an attempt to determine CPP molecular chain length following different stages of the porous construct fabrication. This proved difficult and did not provide conclusive results. However, it was found that the $Q^2$ peaks revealed distinguishing chemical shifts of α, β and γ CPP which provided a useful tool for crystal structure analysis. Samples from different stages of processing to form the porous CPP constructs including 1) after calcining of calcium phosphate monobasic monohydrate to form CPP powder, 2) after melting and quenching of this powder, 3) after a Step-1 sinter anneal at 585°C and 4) after a Step-2 anneal at 950°C were analyzed by SS NMR to determine crystal structure. In vitro degradation studies of CPP samples after different processing anneals were also undertaken. The results of the in vitro degradation studies suggested that degradation rates of CPP can be tailored by varying the Step-2 anneal temperature.

## EXPERIMENTS

CPP processing includes calcining of $Ca(H_2PO_4)_2.H_20$ at 500°C, melting the calcined powders at 1100°C for 1 hour, quenching and grinding to form CPP powder of desired size, and then applying a 2-step sintering anneal treatment to form porous CPP structures. Samples were collected after each step for SS NMR analysis. The $^{31}P$ NMR experiments were performed on a Bruker Avance NMR spectrometer with a 9.4T magnet (162.02 MHz 31P Larmor frequency) using rotors of 4mm diameter. The $^{31}P$ NMR chemical shift scale was referenced externally against $NH_4H_2PO_3$ at 0.81ppm as a secondary reference. The 90 degree pulse time was also determined on this sample. The final 1-d MAS spectra were acquired with a 90 degree pulse of 5.4$\mu$s. Samples were spun at 5.0 and 12.0 kHz to determine spinning sidebands and center bands.

Step-1 sintered 4mm diameter rods were cut into 6mm length and annealed at selected Step-2 temperatures of 650, 720, 835 and 950ºC. After the Step-2 anneal, samples were aged in pH 7.4 PBS solution at 37ºC incubator and weight loss determined after 30 days.

## RESULTS AND DISCUSSION

According to references[2,3], the chemical shifts for $Q^2$ groups of CPP are: -30.7, -31.0, -32.1, -32.6, -33.7, -33.9, -34.3, and -34.8ppm for α-CPP; -29.9, -31.8, -30.3 and -27.3ppm for β-CPP; -28.9, -18.7, -23.6 and -27.0ppm for γ-CPP. The NMR results for the samples after calcining showed peaks at -18.7 and -23.6ppm indicating the existence of γ-CPP with peaks of -27.0 and -28.9ppm buried in the peaks of β-CPP (Fig.1a). After the quenching step, the NMR curve for

amorphous CPP is shown in Fig. 1b. After Step-1 sintering, the structure was mainly β-CPP with a small amount of amorphous and α-CPP (Fig.1c). After the Step-2 anneal at 950ºC, the amorphous and α-CPP disappeared and left only β-CPP with some impurities (peaks at -24, -26 and -35ppm). This is the phase characterizing the porous CPP implants currently being evaluated in bone substitute applications. Fig. 2 shows the weight loss after 30 days in PBS saline of the CPP after Step-1 and after different Step-2 annealing treatments. The degradation rates decreased with increase of Step-2 temperature from about 20% weight loss for no Step-2 anneal to 1% for 950ºC Step-2 anneal sample. This difference is attributed to rate of crystallization and β-phase development for the inorganic CPP polymer. Long chain polymers such as CPP crystallize within a folded chain structure and this provides latitude in control of rate of crystallization and phases that form which in turn determines degradation rate. Studies to further correlate SS NMR findings to degradation rates for the different Step-2 annealing treatments are suggested.

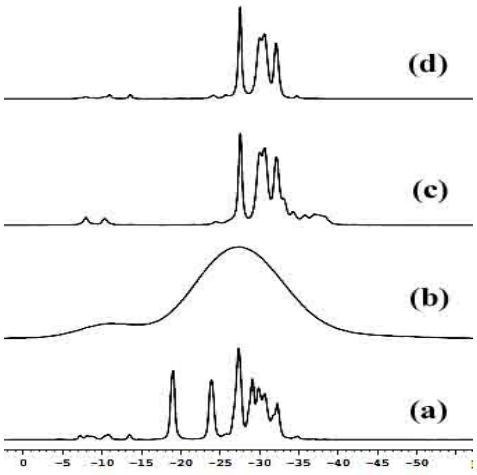


Fig. 1 SS NMR curves of CPP at different processing stages

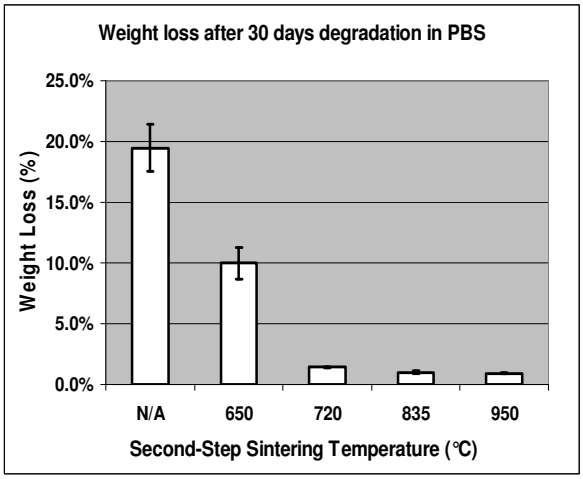


Fig. 2 Weight Losses of CPP at different anneal temperatures after 30 day degradation in 7.4 PBS

## CONCLUSION

SS NMR provides a valuable tool for distinguishing CPP crystal structures. Tailored degradation rates by varying annealing temperatures may have clinical relevance for bone substitutes for different skeletal locations or patient populations.


## ACKNOWLEDGEMENTS

Financial support for this study was provided through grants from the Natural Sciences and Engineering Research Council of Canada (NSERC)


## REFERENCE


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