Reactivity of calcium phosphates

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The in vivo behaviour of calcium phosphate (CaP) bone graft substitutes is determined by many factors, such as the graft architecture and location. However, the most important parameter is the chemical reactivity of the material itself. This reactivity depends not only on the material solubility but also on physical factors such as the presence of surface defects. This talk will attempt to review the current knowledge in the field and try to relate physico-chemical properties to biological properties.

CaP materials that are implanted in vivo are generally resorbed or degraded by cells like macrophages and osteoclasts. This implies that cells are able to dissolve CaP materials or in other words that two conditions are met: (i) the solubility of the material in the local cell environment is high enough and (ii) kinetics aspects are favourable enough to lead to dissolution.

The solubility of most CaP materials is lowest at neutral or slightly basic pH (Fig 1). For example, dicalcium phosphate dihydrate (DCPD), hydroxyapatite (HA) and β-tricalcium phosphate (β-TCP) have their lowest solubility close to pH 8.0, 8.5 and 9.5, respectively. However, solubility strongly increases when the pH values decreases. In fact, most calcium phosphates are insoluble in normal physiological conditions (meaning that CaP materials will not spontaneously dissolve), but are soluble in moderately acid conditions, hence allowing cell-driven dissolution.

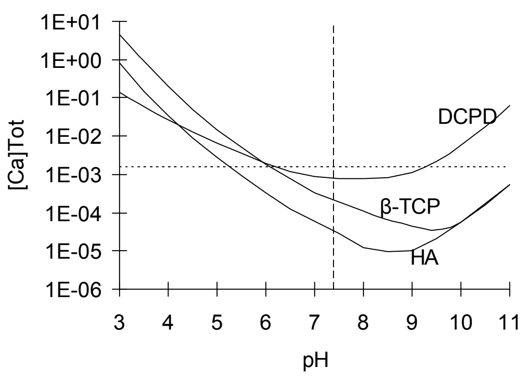

Figure 1: solubility curves (isotherms) of DCPD, HA and β-TCP. The dotted line represents the calcium concentration in serum (roughly 2mM)

As previously mentioned, dissolution of a CaP material in a given solution may not occur even though the material is soluble. Such aspects have been discussed extensively in the scientific literature [1]. Dissolution can only occur if the driving force is large enough. This implies in particular that defects are present at CaP surface or can be easily created [1]. This also implies that the dissolution medium does not contain such strong dissolution inhibitors that dissolution is completely prevented.

Recently, it was found that the dissolution of α-tricalcium phosphate (α-TCP) nanoparticles obtained by calcining amorphous calcium phosphate nanoparticles only started after several hours despite the fact that microsized α-TCP particles are generally used for hydraulic cement reactions [2]. Similarly, thermal treatments of microsized α-TCP performed at a sub-sintering temperature (500ºC) were able to strongly modify the onset of their hydraulic reaction [3]. Both results were attributed to the fact that the thermal treatments were able to remove all surface defects, implying that dissolution (and reaction) could only start after the nucleation of surface defects.

More recent data suggest that the biological reactions of CaP materials might also be affected by such thermal treatments. Specifically, osteoclasts were cultured on α-TCP, β-TCP and HA granules (0.125-0.18mm) obtained by grinding α-TCP, β-TCP and HA solids. The granules were either used as such or after a thermal treatment at 500ºC. The recorded TRAP activity was not only a function of the material but also of the use of a thermal treatment: the TRAP activity was always enhanced on thermally treated granules.

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