Effect of Incorporating $CaSiO_3$ on the Properties of Absorbable, Adhesive Composite Bone Cement/Filler

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Statement of Purpose: Results of a recent study on absorbable bone cements demonstrated the feasibility of producing new, self-setting absorbable adhesive/ phosphate composites with promising properties for use as a bone cement/filler.[1] Meanwhile it has been long recognized that silicon does have a role in neonatal bone formation[2,3] which led to (1) investigating its osseo-promotive capacity to improve the performance of orthopedic biomaterials[4,5] and (2) studying the effect of $CaSiO_3$ on hydroxyapatite formation[6] and (3) preparing a self-setting biphasic $Ca_2SiO_4/CaSO_4$ ½ H_2O composite and evaluating its properties as a bone cement.[7] This and the fact that $CaSiO_3$ is known to have higher solubility than calcium phosphate led to the research question on how will the properties of phosphate-based adhesive bone cement/filler be affected by incorporating $CaSiO_3$. And the present study is designed to answer this question with a focus on the effect of $CaSiO_3$ on the in vitro absorption profile and mechanical properties.

Methods: The absorbable bone cements (ABC) were constructed in a 3 in. x 3 in. Teflon® compression mold, to produce 2 mm-thick sheets. Each ABC was prepared by mixing equal parts of an inorganic powder and liquid methoxypropyl cyanoacrylate (MPC) in a polypropylene container. The inorganic powder consisted of $CaSiO_3$ and/or dibasic calcium phosphate (DBCP). The composition for each system varied from (1) ABC-1 with 100 wt. % dibasic calcium phosphate (DBCP); (2) ABC-4 with ~25:25 wt ratio of DBCP:calcium silicate (CS); and (3) ABC-5 with ~45:5 wt. ratio of DBCP:CS. The cement constituents were mixed for one minute or until homogenous then added to the mold. The mold was placed in a 37°C incubator for curing. After removing the cured composite sheets from the mold, each was cut into 1 cm x 5 cm test specimens and tested to failure by three-point bend on an MTS Snyergie 200. Four experimental specimens were cut from each sheet and tested. To study the effect of *in vitro* degradation, three-sample sets were tested for time periods of 1, 2, and 3.5 months. The samples used were the same as those used for three point bending. They were placed in 12 mLs of deionized water in a 15 mL centrifuge tube. The *in vitro* study was conducted at 50°C. The eluents containing degradation products were changed weekly and their pH was measured. At the end of each period, the remaining solid component was isolated and dried to a constant weight to determine the percent mass loss.

Results: The mechanical properties of the new absorbable bone cements are summarized in Table I. It is to be noted that there is no significant difference in modulus between the ABC-1 and ABC-4 cements. The use of large amounts of calcium silicate did cause a significant decrease in peak stress and toughness (measured in terms of work to break using the area under the stress-strain curve). Meanwhile, the use of a small amount of $CaSiO_3$, as in ABC-5, led to a significant decrease in peak stress and modulus, but moderate decrease in toughness. This may suggest that the DBCP/ $CaSiO_3$ can be subject to optimization. The *in vitro* mass loss data listed in Table II indicate that ABC-1 with 100 wt % DBCP exhibits the slowest degradation profile. In ABC-4, incorporating a large amount of $CaSiO_3$ increased the rate of degradation, especially at the 1- and 2-month time periods. It is hypothesized that the increasing porosity during *in vitro* degradation resulted in a larger surface area which accelerated the rate of degradation. The ABC-4 sample reached ~50 wt % mass loss but degradation slowed down thereafter. This could be partially due to the early loss of CS and DBCP low solubility while leaving a small amount of polymer remaining on the ABC. In ABC-5, with a small amount of $CaSiO_3$, the degradation rates and hence, mass loss increased slowly but steadily. This supports the thesis that there can be an optimum $CaSiO_3$/DBCP ratio

Table I. Mechanical Properties of Silicate-free and Silicate-containing ABCs

Sample Name	Peak Stress (psi)	Modulus (N/mm^2)	Strain at Break (%)	Work to Break ($N\ m\ /\ cm^3$)
ABC-1	320 ± 22	51.9 ± 5.6	5.83 ± 0.80	42.4 ± 11.3
ABC-4	274 ± 38	52.6 ± 3.8	4.90 ± 1.17	28.0 ± 10.6
ABC-5	241 ± 30	33.8 ± 2.2	6.52 ± 0.91	33.8 ± 2.2

Table II. *In Vitro* Mass Loss Data

Samples	Time Period, Months	Mass Loss (%)
ABC-1	1	9.8 ± 0.5
	2	25.3 ± 2.3
	3.5	38.6 ± 2.2
ABC-4	1	43.4 ± 0.4
	2	47.9 ± 2.7
	3.5	49.7 ± 1.2
ABC-5	1	21.6 ± 0.2
	2	38.5 ± 1.5
	3.5	50.0 ± 0.8

Conclusions: Results indicate that incorporating the more soluble bioactive CS shortens the absorption profile of the adhesive bone cement composites with variable changes in their mechanical properties.

References:

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