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Bioactivity of continuous natural mineral fiber reinforced composite pins and plain X3 natural mineral fibers

Arctic Biomaterials Research and Development

Introduction

Conventional bioabsorbable polymer implants have lacked the mechanical properties to be applied in load bearing applications in human body. Bioactive natural mineral reinforced composites offer improved mechanical properties for load bearing applications. Additionally, bioactive natural mineral fiber component is able to form a bone-like apatite layer which enables bone to grow directly to it facilitating bone healing.

This white paper summarizes bioactivity studies done using Arctic Biomaterials' proprietary bioactive X3 natural mineral fiber reinforced composite pins [1] and a dissolution study on plain bioactive X3 natural mineral fibers performed in-house.

Materials and methods

Bioactivity of continuous X3 natural mineral fiber reinforced composite pins was studied in a 78 week long and plain X3 natural mineral fibers in a 104 week long in vitro test study. The matrix polymer of the composites was poly(L-lactide-co-D,L-lactide) (PLDLA) with the comonomer ratio of 80/20 (L to DL-lactide). Plain PLDLA pins were studied as controls. Composite and plain polymer samples were EtO sterilized before the study. Simulated body fluid (SBF) was used as the dissolution medium in all studies. Conditions were 37°C and pH 7.4±0.2. The dissolution medium was changed every two weeks for the pins and every week for the plain fibers. Pins were 50 mm long and their diameter was 2 mm. The fibers had mean diameter of 15 micrometers and the fiber content of the composite pins was 27.5 wt-%. Plain fiber samples were in bundles weighing approximately 1.5g.

At predetermined time points, three pins of each composition (composite and plain polymer) were withdrawn from the solution and tested. SEM/EDX was performed to study the morphology and calcium phosphate deposit formation on the sample surfaces and X-ray diffractometry was performed to analyze the chemical structure and composition of the calcium phosphate deposit. For the plain fibers, SEM/EDX was performed to study the calcium phosphate deposits after the samples had been cast in epoxy.

Results and discussion

Composites

In the SEM/EDX analysis, calcium phosphate (CaP) deposits were observed on the surfaces of all samples. Figure 1 shows the deposit on the natural mineral fiber reinforced composite pin end at 15 week time point. When the deposits on fiber reinforced composites and plain copolymer samples were compared, it was found that only the deposit on the fiber reinforced composite pins showed the properties of bone-like apatite and thus bioactivity. Formation of bone-like apatite layer is seen as proof of bioactivity and the ability to bond to bone [2].

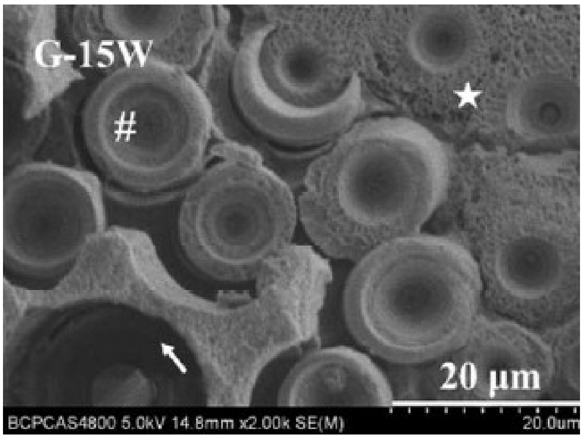

Figure 1. *Calcium phosphate deposit (indicated by star) on the end of natural mineral fiber reinforced composite pin at 15 week time point [1].*

According to Kokubo and Takadama, [3] a material that is able to form apatite (a form of calcium phosphate, CaP) on its surface when immersed in

SBF is also able to form apatite in a living body and bonds to living bone through this apatite layer as long as the material does not contain any toxic or antibody inducing agents. Thus, the apatite forming ability can be considered as proof for bioactivity. According to ISO 23317:2014 [2], the apatite formed in SBF should be similar to the apatite found in bone tissue in following aspects: It has lower Ca/P atomic ratio than stoichiometric apatite, it contains some impurities such as Mg2+, Na+, Cl-, HCO3- and it has low crystallinity. The stoichiometric Ca/P ratio in hydroxy apatite and apatite is 1,66.

The ratio of calcium to phosphate indicated that the deposits on the natural mineral fiber reinforced pins were bone-like apatite and in addition the deposits were doped with trace amounts of magnesium and sodium (Figure 2, points 1 and 2). Low crystallinity of the deposit was also observed. As comparison, the CaP deposit on the surface of plain polymer pins had Ca/P ratio of 1.82.

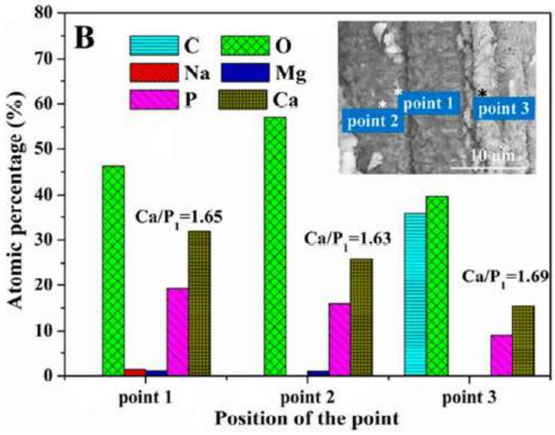

Figure 2. Ratio of calcium to phosphate on the surface deposit at three locations of the natural mineral fiber reinforced composite pin at 78 weeks [1].

X3 natural mineral fibers

The results of the plain natural mineral fiber dissolution tests showed that CaP layer was formed around the natural mineral fibers. The deposits are shown in Figure 3 and EXD analysis of the CaP layer in Figure 4. When the Ca/P ratio of the deposited clusters was studied, it was noticed that it decreased with time from 3.2 at 26 weeks to 1.61 at 104 weeks. This is slightly lower than the stoichiometric Ca/P ratio of apatite and thus corresponds to the requirements of ISO 23317:2014 [2]. Additionally, sodium, chlorine, magnesium, carbon and oxygen were found, which also match with the properties of biological apatite. The crystallinity of the deposits was not studied in this study. However, these results suggest that the CaP layer is matured to apatite with time.

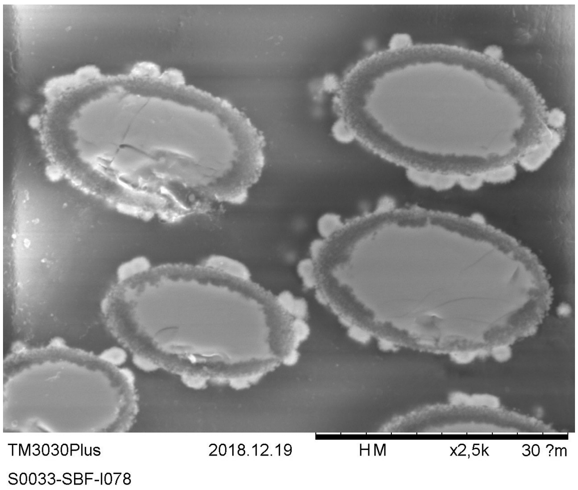

Figure 3. Natural mineral fiber cross section at 78 weeks in vitro.

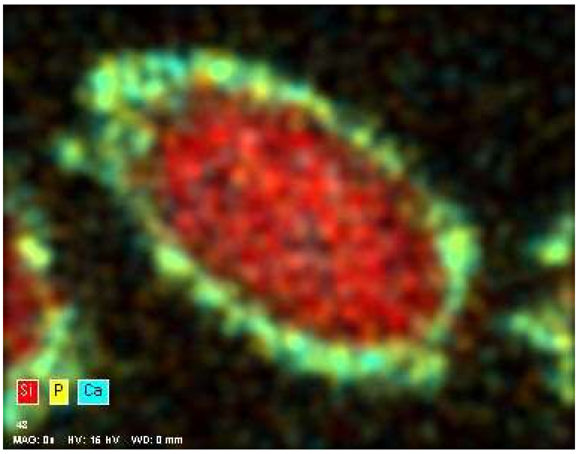

Figure 4. EDX analysis of the 52 week time point natural mineral fiber cross section showing the CaP layer on the surface (Ca in blue and P in yellow).

Conclusions

These studies demonstrated bone-like apatite layer deposition on the natural mineral fiber reinforced pins and plain X3 natural mineral fibers and the deposit was similar to bone mineral. The results indicate that the X3 bioactive natural mineral fibers in the composite enhance bioactivity.

References

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3. Kokubo, T., Takadama, H., How useful is SBF in predicting in vivo bone bioactivity, Biomaterials, 2006.