MICRO-CT IMAGING OF BIOACTIVE ACRYLIC BONE CEMENT COMPOSITE

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Introduction

In knee and hip replacements, acrylic bone cements are generally used in the fixation of implants. Conventional acrylic bone cements do not allow bonding bone ongrowth and ingrowth tightly into the cement layer, because the structure does not contain porosity. If the fixation is only mechanical, the micromotion between the bone and implant interface can lead to resorption of bone and possibly loosening of the prosthesis [1].
If the acrylic layer was porous and bioactive, it would stimulate bone ingrowth to the cement structure [2]. Therefore, the focus of our studies is to modify biostable bone cements in order to improve their biological properties, for example, by creating porosity and bioactive structure in the cement matrix [3]. Bioactive glasses (BAG) are a group of surface reactive glass-ceramics that display the characteristics of bioactivity [4]. If bioactive glass fillers are added into acrylic polymer matrix, the interfacial properties of these two types of material categories should be adjusted using coupling agent system.
In this study, a preliminary survey was done to find out whether the presence of 3-methacryloxypropyltrimethoxysilane (MPS) as a co-monomer in a two-liquid monomer system of acrylic bone cement increases the adhesion between BAG and matrix polymer of acrylic bone cement, while resulting the formation of interconnected porosity in the wet conditions.

Experimental

The powder component of autopolymerizing acrylic bone cement (Palacos®R, Schering-Plough, Heist-op-den-Berg, Belgium) was used as such in the preparation of one half of the specimens. In the other half of the specimens, it was mixed with the bioactive glass granules (BAG, BonAlive™, S53P4, composition: SiO_2 53%, Na_2O 23%, CaO 20% and P_2O_5 4%, Ø315-505µm, Vivoxid Ltd., Turku, Finland). Subsequently, an experimental two-liquid monomer system containing methyl methacrylate (MMA) and 3-methacryloxypropyltrimethoxysilane (MPS, 98%, Sigma-Aldrich Ltd., Steinheim, Germany) was mixed with the powder component for 5 min. For preparing the set of bone cement matrices (*i.e.* one half of the specimens), the monomer system of acrylic bone cement contained either 0, 12.5, 25, 37.5, 50, 62.5 or 75 wt% of MPS. Hence, the prepared test specimens contained totally 68 wt% of Palacos®R powder component and 32 wt% of experimental monomer system. The other half of the specimens had the same matrix polymers, but the prepared test specimens additionally contained 30 wt% of BAG. No additional initiator and activator of autopolymerisation reaction (based on the materials obtained from Palacos®R) were added in the preparation of test specimens. The prepared specimens were allowed to cure under NTP conditions in the shape of cylinders (diameter: 4.5mm and height: 9mm). The specimens were divided in 7 groups (N=6/ test group). Two different storing conditions were applied, *i.e.* dry and immersing in simulated body fluid (SBF) at +37°C for 5 weeks.
The morphology of the composites was evaluated by scanning electron microscopy (SEM, JSM-5600, JEOL, Japan). The 3D structure of the composite was evaluated by micro-computed tomography (micro-CT). Micro-CT imaging was performed with the spatial resolution of 5.23 µm/voxel. Source voltage was 72 kV and source current was 138 µA. Angular step was 0.45 degrees, within the total angular range of 180 degrees. At each angular step a shadow projection 16bit image was taken. This image was an average of two consequent imaging. The shadow projection images were reconstructed into a stack of cross-sectional images using NRecon software (SkyScan, Belgium). A 4-mm thick cylindrical volume of interest (VOI) was selected within the stack of cross-sectional images and analyzed using CTAn software (SkyScan, Belgium).

Results and Discussion

The bioactive substances increase the bone ingrowth into the acrylic bone cement, if the structure is porous from its outermost surface. In these composite structures, the porous phase is possible to be formed using hydrophilic filler particles (porogens).
According to the results of this study, if the specimens were stored in dry conditions, the amounts (<25wt%) of MPS in the monomer system increased the compression strength of plain bone cement matrix. However, the

amounts of MPS (25-75wt%) in the monomer system as well as the water sorption into the specimens decreased the compression strength. In dry conditions, the presence of silane groups in acrylic bone cement did not increase the adhesion between BAG and matrix polymer. Normally, if silane molecules are utilized in adhesion of two materials, they first will be activated by hydrolyzing the methoxy groups to become silanol groups [5]. Therefore, the test specimens of this study were also subjected to wet conditions. The water sorption study revealed that the diffusion of water most likely caused the hydrolysis reaction of silane groups. Namely, if the specimens were allowed to be immersed in water for 5 weeks, the compression strength increased in the specimens containing BAG granules (~5-10 MPa per test group) compared to the same specimens stored and measured in dry conditions. Hence, during the sorption test, the hydrolysis reaction caused the formation of silanol groups that further increased the adhesion between BAG and polymer matrix.

In addition, the diffusion of water into the test specimens containing 30 wt% of BAG and hybrid polymer matrix was noticed to cause the formation of a porous structure. **Fig. 1 and 2** show the structure of acrylic bone cement that contained 75 wt% of MPS in its monomer system and 30 wt% of BAG granules. After the immersion of specimens in SBF for 5 weeks, it was noticed that water sorption caused an evident porous structure formation. Additionally, there was also minor CaP formation. Average surface pore size obtained from image analysis of SEM micrographs seemed to be between 100 and 500 μm, which were randomly distributed in the matrix.

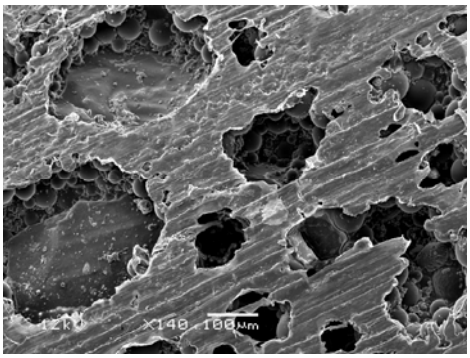

Fig. 1 The outermost surface of bone cement matrix that contained 75 wt% of MPS on its monomer system and 30 wt% of BAG, after 5 weeks storing in wet conditions (magnification x 140).

According to the images of micro-CT, the porous structure in the biostable polymer network seemed to be relatively homogenously distributed. The micro-CT analysis revealed different pore shape and size formation as a result of the sorption of water, which was dependent on the amount of MPS in monomer system. A higher amount of MPS turned out to form more porosity on the structure. In the case of 75 wt% of MPS in its monomer system and 30 wt% of BAG granules, the total porosity of the quantitative micro-CT analysis was 17.7%, of which open porosity (interconnected pores) was 10.5%

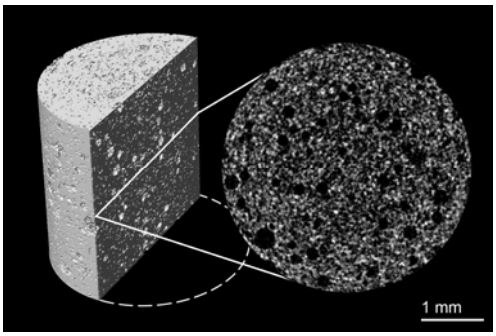

Fig. 2 A three-dimensional surface rendering of VOI is shown on the left. A cross-sectional image of the material is shown on the right: white color represents bioactive glass granules, grey color represents polymer matrix and black color represents pores.

Conclusion

Within the limitations of this study: The addition of MPS as co-monomer in acrylic bone cement as a composite with BAG caused the porosity formation in wet conditions. The modified structure had improved capability to absorb water that simultaneously ensured the increased adhesion between BAG and matrix polymer.

References

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