HOW TO STIMULATE POLYMERIC SURFACES BIOCOMPATIBILITY AND HYDROXYAPATITE FORMATION: EXPERIMENTS SUPPORTED BY MD SIMULATIONS

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Introduction

Polymers have been widely used for the last 3 decades in medical applications, such as coated transducers, neural prosthesis, catheters, and parts of orthopedic implants. Because of a plethora of existing possibilities, three questions need to be addressed in order to obtain the biomaterial tailored for the desired site in the body: (a) what is the required function? (b) Should functional groups be introduced? If yes, which one? (c) What is the most effective surface coverage?

For the biocompatibility of the adherent cells, such as osteoblasts, polymeric surfaces can be successfully transformed from hydrophobic to hydrophilic using oxygen plasma treatment. This modification results in the introduction of oxygen-containing functional groups (−OH, −CHO, −COOH). Such functionalities have been described to be crucial for initial steps of osteogenesis, which induces wound healing and consequently osseointegration

This study aimed to gain an in-depth molecular insight into the experimentally observed changes in surface wettability and nucleation of calcium phosphate at the functionalized polymer−body fluid interface. We employ the molecular dynamics simulations to reveal the role of surface functional groups formed during the oxygen plasma treatment in the biocompatibility and mechanism of calcium phosphate formation.

Materials and Methods

To modify the polymeric surfaces, oxygen plasma treatment was carried out using a Diener electronic Femto plasma system (Diener Electronic) at 50 W and an oxygen partial pressure of 0.2 mbar [1]. The samples were characterized with the use of spectroscopic (RS, IR, XPS), microscopic (fluorescence microscopy, SEM), and biological (microbiological, cell culture, in-vitro SBF incubation) methods. The atomistic MD simulations were performed according to our published models [2,3]. Four different functional groups, corresponding to different ways of surface modification, were considered, namely, −OH, −CHO, and $-COO^-$.

Results and Discussion

Upon oxygen plasma treatment, the originally hydrophobic polymeric surfaces (Θ_w=90°) turn hydrophilic with a dramatic decrease of water contact angle value to Θ_w=0.1°. As a consequence, significant differences were observed in the case of the calculated values of Surface Free Energy (SFE) as well as their corresponding polar (γ_s^p) and dispersive (γ_s^d) components. Initially, the SFE of unmodified polymer is 43.7 mJ/m^2 and consists mostly of dispersive component (43.1 mJ/m^2) with minimal polar influence (0.6 mJ/m^2). Modification with oxygen plasma and incorporation of oxygen-containing surface functional groups cause a significant increase of the SFE value to 74.2 mJ/m^2. The role of the dispersive component diminishes to 26.5 mJ/m^2, while the polar component becomes dominant with 46.6 mJ/m^2. This founding has an important significance for the modified polymeric surface; the experimentally obtained ratio of dispersive and polar components γ_s^d/γ_s^p = 0.5 is in line with the theoretically determined 60% surface coverage for −OH, such that the corresponding ratio of dispersive and electrostatic energies ($E_{dispersive}/E_{electrostatic}$) is 0.56. Such optimized modification with oxygen-containing surface groups significantly enhances the interactions between body fluid ions and the polymeric surfaces, observed experimentally as calcium phosphate formation. The results were discussed in terms of MD simulations of the calcium phosphate clustering (FIG. 1).

Surface functional groups promote the clustering of calcium and phosphate ions in the following order: −OH > −CHO > −Cl (unmodified polymer) ≈ −COO−. This promoting role of surface functional groups is explained as stimulating the number of Ca^{2+} and HPO_4^{2-} surface contacts as well as ion chemisorption.

Conclusions

In the study, the superiority of the −OH groups (50% coverage) was identified as the most effective sites for calcium phosphate nucleation. The advantage of the combined experimental and theoretical approach is pointed out as effective for biointerface design and fabrication.

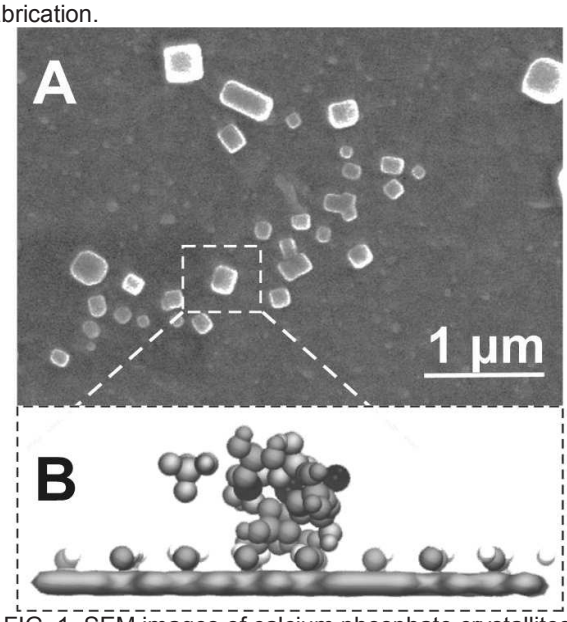

FIG. 1. SEM images of calcium phosphate crystallites formed on oxygen-plasma modified polymeric surface (A) and characteristic MD snapshot presenting the last stage of the calcium phosphate nucleation process (B).

Acknowledgments

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References

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