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Effect of Magnetic Field on Biomimetic Coating of Hydroxyapatite on Titanium

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Hydroxyapatite (HA) coating for orthopedic and dental implants does accelerates the bone apposition period. A simple and well adherent coating is possible using biomimetic process, which mimic natural process of HA precipitation in body fluid. Efforts were made to accelerate the coating process duration by increasing the concentration of ions of simulated body fluids. Magnetic therapy has been proven to accelerate the recuperation of patients from fracture and orthopedic ailments. The concept has been applied to biomimetic coating and studied the influence of magnetic field on coating characteristics. Commercially pure titanium of 200 microns thick samples of dimensions 10 x 20 was surface treated by sodium hydroxide treatment (10M NaOH aqueous solution at 80°C for 24 hrs). The samples where immersed in 5 X SBF solution for two weeks. Normal HA coating were compared with the HA coating under permanent magnetic field. The X-ray diffraction (XRD) and Fourier transformed infrared spectroscopy has characterized HA. Scanning electron microscopy (SEM) has shown better dense and finer coating in case of HA coating under magnetic field than normal HA coating.

Introduction

Titanium is a material that is used frequently for *in vivo* orthopedic implants such as hip prostheses and bone screws. The excellent mechanical properties and inert nature of this material make it desirable for restoring structural integrity to hard tissue that has undergone physical or pathogen-related trauma [1]. The lack of interaction with the biological environment prevents the implant from integrating with the surrounding hard tissue. Osteoconductivity, may occur if a layer of bone-like mineral forms on the surface of the implant. Hydroxyapatite (HA) have been coated to orthopedic implants dramatically enhance hard tissue integration, thereby increasing the mechanical stabilization *in situ* [2]. This hard tissue integration and stabilization may lead to quicker patient recovery times and extended life for orthopedic implants [3]. Currently metallic implants are coated with HA by plasma spraying are in use. But problems associated with such high temperature process is formation of morphology and crystal structure of the HA, which can negatively affect osteoblast adhesion [2]. The process has difficulty in coating complex geometry. A simple method that mimics apatite formation (biomineralisation) on biomaterial inside body has been studied recently and showed promising results [4]. The processes adapted have solution composition similar to blood plasma at 36.5°C and pH 7.4, called simulated body fluid (SBF). Among the various recipes available Kokubo's and Hank's balanced salt solution are two commonly used SBFs. The process takes longer time for coating formation. To overcome this supersaturated calcium phosphate solution (SCPS) with a buffer to elevate and maintain the pH to near physiologically neutral levels [5].

The electro magnetic therapy has been used in orthopedic field has been used to reduce the pain and accelerate the restoration period. Electromagnetic fields alter the effects of hormones on the cell membranes, and increase production of growth factors and receptors, affect calcium flux across membranes, and stimulate endothelial cell proliferation and capillary formation [6]. Use of permanent magnets with north pole proximity seems to relieves pain, swelling, promotes tissue alkalinization, promotes sound, restful sleep and increases tissue oxygenation. Whereas south pole accelerates growth, increases swelling, promotes tissue acidity and decreases tissue oxygenation. Extremely low frequency electromagnetic fields (ELF-EM) electric field of frequency of 324 Hz increases crystal growth rate of HA by 40% in *in-vitro* biomineralisation [7]. EM-ELF of 3mT and 1300 Hz in frequency results in precipitation HA from supersaturated solution shows lower specific surface are and larger average grain size than HA produced from with no ELF-EM. Thus an EM-ELF force interacts with colloidal-like particles at beginning of the nucleation process due to increased interfacial solid/liquid energy [8]. The magnetic field of 0.1 Tesla has shown to accelerate the diffusion and rate of reaction of HA formation [9]. In this work, influence of magnetic field on biomimetic HA coating has been investigated.

Experimental Details

Commercially pure titanium sheet (Titan-12 Grade 1, 200 microns, MIDHANI) was used for HA biomimetic coating. The Ti sheets were alkali treated as reported [10]. The sheet was immersed in 5 SBF solution with composition reported elsewhere maintained at 36.5°C [11]. A permanent $Nd_2Fe_{14}B$ bar magnet magnetized along thickness kept as shown in fig 1. The field strength is 0.1 Tesla near the surface was measured by Gauss meter. After 3 days of immersion the sheets with coating and sediments were removed from solution and oven dried. Coatings were carried out with north pole proximity, south pole proximity and without magnet. The coating was studied by X-Ray powder diffraction (XRD) method (Shimadzu XD-D1, Japan) using CuK$_\alpha$ radiation and the sediments were studied by Fourier-transform infrared spectrometer (FT-IR) (Perkin Elmer Spectrum One, USA) at 4000-400 cm^{-1} region by using KBr pellet technique. The coating was observed under a scanning electron microscopy (JOEL JSM 5410 & JSM 5300, Japan) after coating with a thin gold film.

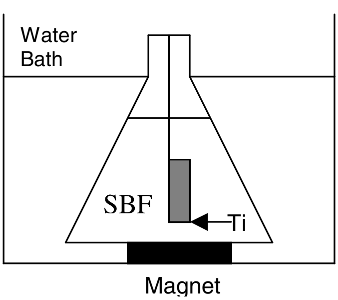


Figure 1 : Experimental set up

Results and Discussion

The XRD pattern of HA coated Ti shows peaks corresponding to HA (JCPDS 9-432) and that of Ti (JCPDS 44-1294) as shown in Fig. 2. The peak broadening of HA is characteristic of nanocrystalline HA which is the nature of biomimetic coating [2].

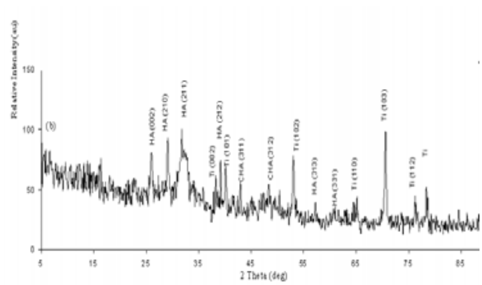


Figure 2 : Typical XRD pattern of HA coated Ti

The characteristic functional groups corresponding vibration of phosphate ion, hydroxyl ion, adsorbed water and carbonated ions were observed for HA powder (Fig 3). Similar to results on effect of magnetic field on HA

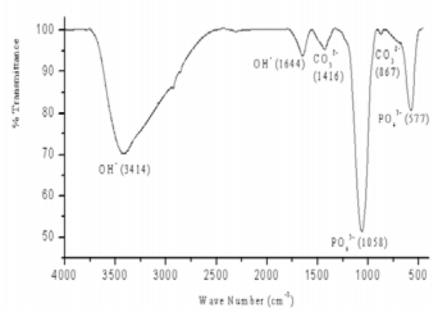
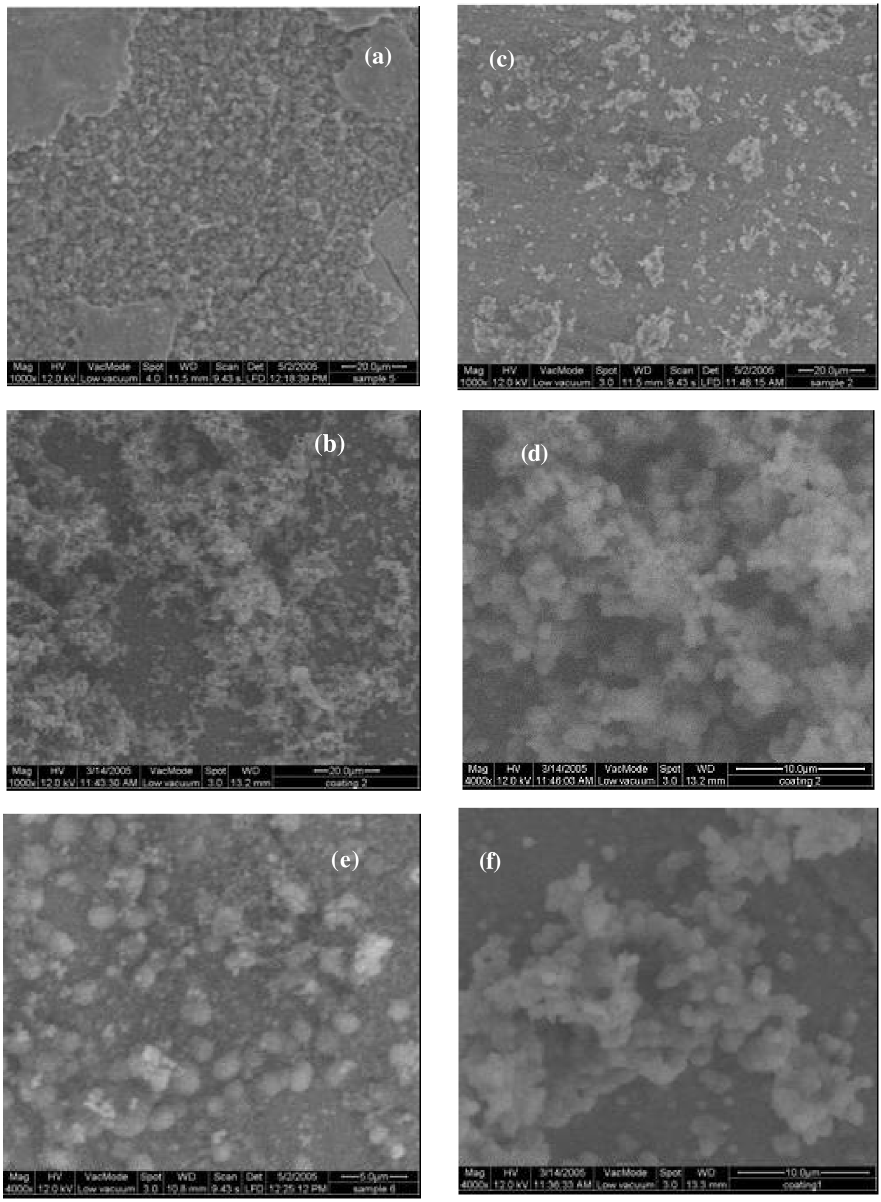


Figure 3 : Typical FT-IR spectra of HA powder

precipitation, coating using north pole, south pole and without magnetic field did not show any variation without respect to structure and composition based on XRD and FT-IR studies [7].

The SEM micrographs shown in Fig 4 shows distinct variation among the three set of coating. The north pole proximity HA coating is more dense than without magnet than coating with south pole proximity coating. High magnification



Figue 4 : SEM Micrographs of biomimetic coating with (a) & (d) north pole proximity; (b) & (e) with no magnet and (c)& (f) south pole proximity

micrograph shows finer globular HA coatings in case of north pole proximity coating than without magnet than south pole proximity coating.

The mechanism of biomimetic coating is by sequence of amorphous phase formation on titanate layer and which in turn act as site of nucleation followed by HA precipitation resulting globular structure [10]. The more porous coating is observed in north pole proximity coating than without magnet than south pole proximity coating. As reported the nucleation is accelerated in north pole proximity coating by magnetic field aiding in calcium ion diffusion and playing positive role in reaction kinetics resulting in dense and finer coating [6,8]. South pole proximity coating shows negative role of magnetic field in HA precipitation resulting in scarce coating. The coating without magnet field is similar to reported data with uniform coating.

Conclusion

There is observed to be strong influence of permanent magnetic field of 0.1 Tesla in HA biomimetic coating. North pole proximity coating depicts dense and finer coating than coating without magnetic field than south pole proximity coating. The influence of magnetic field on calcium ion transport, interfacial surface energy and nucleation of HA which is reported for HA precipitation is observed to play role in HA biomimetic coating too. The difference arising from north pole and south pole proximity needs further investigation for understanding the mechanism.

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