Electrochemical Synthesis of Copper Nanoparticles on Hydroxyapatite Coatings for Antibacterial Implants

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The coating of metals with thin ceramic layers is used to reduce the rate of corrosion, add a thermal insulating barrier, or enhance biological activity, among other applications. In this study, coatings of the calcium phosphate ceramic hydroxyapatite (HA) were applied to titanium, and then copper nanoparticles were added to provide antibacterial activity. Synthetic HA has a similar chemical composition to the natural HA found in the mineral component of bone tissue. Coatings of HA on titanium are known to enhance the rate under which an orthopedic or dental implant integrates with surrounding bone. In implant surgery, prophylactic antibiotics are typically used to reduce the potential for post-surgical bone infection. However, the use of antibiotics is undesirable because of the development of resistant strains of bacteria. Metal nanoparticles, such as those reported here, offer a route to provide antibacterial activity without the risk of creating antibiotic-resistant strains of bacteria.

In the present study, a method called cathodic electrolytic deposition was used to synthesize nanoscale HA coatings.[1] Our previous work demonstrated a novel two-stage approach to synthesize silver-hydroxyapatite composite coatings.[2] The cathodic electrolytic process was used in the first stage to synthesize HA on titanium. The HA-coated titanium was then used as the cathode in a second-stage reaction to electrochemically reduce silver ions in solution. The process produced an HA coating decorated with silver nanoparticles, and the silver particles were shown to impart antibacterial activity. While silver is known to be a potent antimicrobial agent, it does pose a risk of toxicity to mammalian cells at high concentrations. In the present study, a similar two-stage synthesis approach was used to create composite copper–hydroxyapatite (Cu–HA) coatings. Copper was chosen because it has the potential for antibacterial activity while being less toxic to other healthy cells.

Figure 1 shows electron microscopy images of Cu–HA coatings produced using varying concentrations of Cu salt in the electrolyte solution used during the second-stage reaction. The HA crystals are visible as nanoscale rods in all images. At the highest Cu salt concentrations, the metallic copper is deposited as a mixture of nanoparticles and larger dendrite structure, as seen in Figs. 1(a) and 1(b). At lower Cu salt concentrations, the number of dendrites declines and, primarily, Cu nanoparticles are synthesized, as seen in Figs. 1(c) and 1(d). The presence of HA was confirmed using x-ray diffraction, and metallic Cu and copper oxide were confirmed on the surface using x-ray photoelectron microscopy.

A series of Cu–HA coatings was made having varying copper content, and the growth of the bacteria *E. coli* and *S. aureus* was measured in the presence of these coatings. It was found that the number of bacteria colony forming units declined with increasing copper content in the coatings. With the highest measured copper content of 6.6 at. %, the number of colony-forming units remaining after 8 h of cell culture declined 78% for *E. coli* and 83% for *S. aureus*.

The results show that the copper nanoparticles are effective at killing a fraction of the bacteria but do not provide a means to completely sterilize an infected surface. Compared to our prior work,[2] copper is less effective than silver in killing bacteria. Copper offers the advantage, however, of less toxicity than silver toward healthy cells. The composite coatings synthesized here

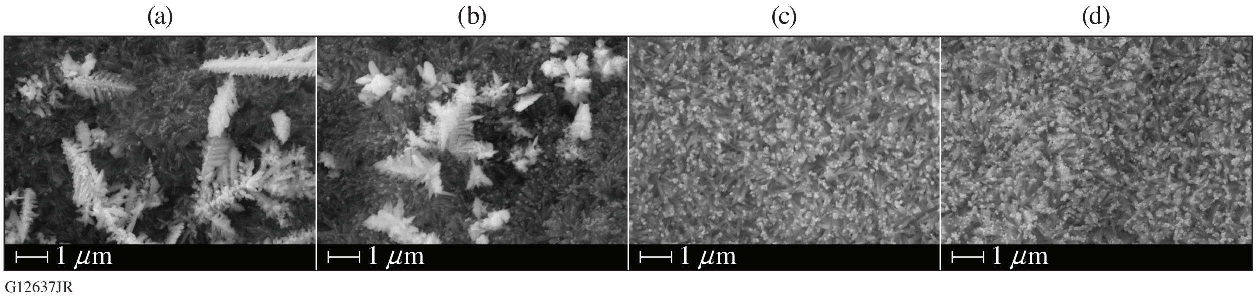

Figure 1
SEM images of Cu–HA composite coatings formed by an electrochemical copper reduction reaction using 12.8-mA/cm^2 current applied for 7 min with a $CuSO_4$ concentration in the electrolyte of (a) 0.625 mM, (b) 0.5 mM, (c) 0.375 mM, and (d) 0.25 mM.

may, therefore, offer a lower-risk route to reducing or eliminating the need for prophylactic antibiotic use in orthopedic implant surgery. In an otherwise sterile surgical environment, the number of bacteria present is expected to be low. Copper on the surface of the implant may reduce the likelihood that any bacteria present develop into a bone infection at the implant surface.

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1. I. Zhitomirsky, Adv. Colloid Interface Sci. **97**, 279 (2002).

2. C. Fu *et al*., Surf. Coat. Technol. **301**, 13 (2016).