Preventing Bacterial Infections using Metal Oxides Nanocoatings on Bone Implant

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Abstract. Nowadays bone implant removal is caused by infection that occurs around it possibly acquired after surgery or during hospitalization. The purpose of this study was to reveal some metal oxides applied as coatings on bone implant thus limiting the usual antibiotics-resistant bacteria colonization. Therefore ZnO, TiO₂, and CuO were synthesized and structurally and morphologically analyzed in order to use them as an alternative antimicrobial agents deposited on bone implant. XRD, SEM, and FTIR characterization techniques were used to identify structure and texture of these nanoscaled metal oxides. These metal oxides nanocoatings on implant surface play a big role in preventing bacterial infection and reducing surgical complications.

1. Introduction

It is well known that from decades nosocomial infections are present in hospitals affecting seriously most of patients. This ancient problem regarding microbial infections is caused by high drug resistance of pathogenic bacteria (gram positive and gram negative) to antibiotics. Many researches focused on finding different methods and materials for fighting infections caused by resistant microorganisms. There are several factors involving microorganism load, surgical technique and type of implant that influence infection appearance on bone implant surface inducing sometimes septic complications. This risk implies patients presenting co-morbidities that could increase the probability of infection.

Nanotechnology offers the opportunity to develop a wide variety of nanomaterials with specific use in medical area especially in limiting damages caused by pathogen microbes.

Moreover, structural and textural features of implant such as material, size, shape and intended use have an important role in this field of medicine. Researcher’s attention in focused on finding implant coatings acting as antimicrobial agents and able to reduce bacterial adhesion and proliferation of the surrounding tissue [1,2].

It is well known that prophylactic antibiotics are administrated to patients undergoing surgery in order to prevent postoperative infection, being well aware that antibiotics has some disadvantages including compliance time of drug administration and the reduced ability to kill pathogenic germs present at the implant-surrounding tissue interface.

Structural and surface characteristics of an implant such as electrostatic charge, porosity and hydrophobicity play a major role knowing that microorganisms have an interesting strategy to adhere and colonize all natural and synthetic surfaces [3,4]. Therefore, researchers should look for solution to avoid bacteria colonization on the implant surface and to create a barrier on its surface in contact with...
living tissue especially applied to the patients with compromise immunity and patients whose risk of infection is greatly increased [5-7].

Bone implants are constantly subject to improvement in bone interaction to ensure the success regarding orthopedic surgery. Textural and structural surface characteristics of metal oxides thin films used as nanocoatings such as morphology, topography and chemistry can represent important tailoring tools to enhance biological action at the bone implant – tissue interface. It is well known that surrounding biological area is affected by the coated titanium implant wettability requiring a long term osseointegration and a good biological environment including the prevention of bacteria multiplication on hard and soft surrounding tissue.

![Image](image_url)

**Figure 1.** Representation on implant-tissue interactions at macro-, micro- and nanometric level.

Bacterial adhesion and multiplication on bone implant may cause a severe disease that leads to bone re-sorption and in special cases the need to remove the implant. Several studies take into account a major interest in designing implants with antimicrobial nanocoatings acting independently or synergistically with the antibiotic administered to limit bacterial infection [8].

A wide range of nanomaterials and technologies were developed and tested as antibacterial nanocoatings. For their manufacturing were been considered certain aspects such as biocompatibility, anti-infective efficiency, durability and resistance to mechanical stresses during surgery and postoperatively respectively [9,10].

Recent researches propose suitable implant coatings possessing multifunctional surfaces and acting as antimicrobial agents with specific properties [11]. Figure 2 reveals most important properties of an antimicrobial coated bone implant.

Nowadays, implant nanostructured coatings are of great interest especially those inhibiting bacteria adhesion and colonization. Among them, silver nanoparticles and some metal oxides used as nanocoatings proved to be suitable to prevent infection of medical device type bone implant [12-16].

When the content of metal oxides is adequate, the antibacterial effect of implant coating can be carried out. The amount of ZnO, TiO$_2$ and CuO metal oxides can be controlled in order to check the bactericidal degree of these thin films used as bone implant coatings.
Different methods were used for preparing CuO, ZnO and TiO₂ metal oxides used as nanocoatings on bone implant in order to prevent bacterial infection.

2. Experimental procedures

2.1. Synthesis of CuO thin film on bioglass
Sol-gel method was used to obtain thin films of bioglass dopped with copper oxides with different percentages of oxides as follows: 6% P₂O₅, 26% CaO, 48% SiO₂ and 20% CuO. The first step consist in the hydrolysis of tetraethyl orthosilicate (19 mL of bioglass containing 20% of copper oxide) catalyzed with 30 mL HNO₃ of 0.1M and stirred for 1 h. The other reagents including tetraethyl phosphate, calcium nitrate tetrahydrate and copper (II) acetate monohydrate (1.7 g) were added to obtain the sol which completed hydrolysis at room temperature for 2h. The resulting sol was kept at room temperature for 10 days to get the gel using ultrasonic procedure for 30 minutes. After this step, the final gel was dried at 60ºC for 25 h and the applied a heat treatment at 600ºC for 6 hours. Finally, the obtained sample was ground to obtain the nanopowders for further characterization.

2.2. Synthesis of TiO₂ thin layers on bioglass
Spray pyrolysis method was used for TiO₂ thin layers obtaining. Great advantages of the method are that thin layers are rough, can be obtained on large surfaces and most important, at low costs. 0.5 mL of TiCl₄ used as precursor was dissolved in a 5 mL solution of ethanol and spryed on a heated substrate of glass were the pyrolytic rection take place, thus obtaining nanocrystalline metal oxide. The deposition was performed at atmospheric pressure to obtain thermodynamically stable phases of TiO₂ then thin layers were calcinated at 500ºC for 5 hours.

2.3. Synthesis of ZnO thin films
Sol-gel synthesis was used to prepare zinc oxide thin films. Zinc acetate dihydrate used as precursor was dissolved in a 0.75 mol/L mixed solution of ethanol and monoethanolamine. The obtained film was thermally treated at 600ºC for 2 hours thus obtaining crystallized ZnO ready to undergo physicochemical characterization.

For further characterization of the obtained metal oxides thin films were used XRD, SEM and FTIR techniques.

3. Results and discussions
XRD patterns (figure 3a) of ZnO correspond to the diffraction peaks (100), (101) and (102) exhibiting growth crystallites of zinc oxide. For CuO sample it can be observed in figure 3c oriented peaks at 2Θ equal to 35.6° and 38.6° corresponding to the reflections (-111) and (111) respectively. Crystalline
nature of CuO increased under reduced atmosphere in oxidation process. In case of TiO$_2$ the diffraction peaks shown in figure 3b are well defined at 2\(\theta\) corresponding to the planes (101) and (111).

![Figure 3](image3.png)

**Figure 3.** XRD pattern of as synthesized samples: a) ZnO; b) TiO$_2$; c) CuO.

Scanning electron microscopy (SEM) was used to provide details regarding textural characteristics of metal oxides thin films at nanometric level. This technique is very important for revealing metal oxides thin films morphology. Figure 4a shows morphological characteristics of CuO multilayer nanoclusters hierarchically arranged having 15-25 nm in width that covers the glass surface.

![Figure 4](image4.png)

**Figure 4.** SEM images of metal oxides thin films.

ZnO images (figure 4b) shows irregular ZnO rods with high surface area and small rod shaped crystals. SEM features of TiO$_2$ thin films (figure 4c) reveals a smooth surface covered with a granular and uniform surface.

![Figure 5](image5.png)

**Figure 5.** FTIR spectra of thin films: a) ZnO; b) TiO$_2$ and c) CuO.

FTIR spectrum of CuO sample (figure 5a) indicates the presence of –OH groups at 3363 cm$^{-1}$, O-H bending vibration associated with Cu atoms can be observed at around 1624 cm$^{-1}$ – 1102 cm$^{-1}$ absorption peaks. Broad absorption peaks at 600 cm$^{-1}$ and 520 cm$^{-1}$ are attributed to Cu-O stretching suggesting the presence of copper oxide and incorporated water in this structure. Absorption peaks of zinc oxide sample are shown in figure 5b. ZnO stretching vibration can be observed at 483.5 cm$^{-1}$ absorption band. Absorption peak at 1424.5 cm$^{-1}$ is associated with C-O stretching and around 3443 cm$^{-1}$ is attributed to O-H groups present in the film. The absorption band at around 1222.5 cm$^{-1}$ may
correspond to acetic acid presence. For TiO$_2$ sample, IR spectra presented in figure 5c show the presence of TiO$_2$ at 610 cm$^{-1}$ and 740 cm$^{-1}$ absorption peaks.

FTIR spectra of synthesized CuO, ZnO and TiO$_2$ thin films suggest the presence of metal oxides bonds.

4. Conclusions

Worldwide healthcare people are aware that prevention is the best solution for bone implant infection. A few factors can influence the osseointegration and infection appearance regarding bone implant. Particularly, modification of bone implant surface by coating with metal oxides thin films results in improving clinical aspects by enhancing osseointegration and preventing infections at the bone implant-surrounding tissue interface.

Presently, antibiotics treatment for infection caused by bone implant may require device removal and elaborated procedures to restore damaged surrounding tissue. The use of nanoscaled metal oxides thin films to coat bone implants is a good option for osseoconduction and bactericidal effect to prevent this stringent problem. The major purpose for this study was to synthesize and characterize metal oxides thin films using advanced techniques for their subsequent applications as nanocoatings on bone implant.

Researches on antibacterial nanocoatings have proved the efficiency of metal or metal oxides deposited on implant surfaces. As ZnO, TiO$_2$ and CuO thin films used as nanocoatings on titanium implant already demonstrated their biocompatibility they can be suitable for deposition on bone implant in order to improve osseointegration in same time with limiting the adhesion and multiplication of pathogenic bacteria.

CuO, TiO$_2$, ZnO metal oxides plays an important role due to their biocompatibility and well adherence on implant improving the performance of this medical device and making it more efficient. Metal oxides nanocoatings on bone implant improve osseointegration enhancing its safety and antibacterial efficacy.

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