Nanoparticles Deposition on Mini-implants for Osseo-integration and Antibacterial Properties Improvement

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In last few years, researchers focused on improvement of lifespan of dental mini-implants by coating them with nanopoarticles for a better osseo-integration, which also possesses antibacterial properties. Once their surface is coated with nanoparticles type silver dopped hydroxyapatite makes them durable and safe by a good integration into tissue and by preventing bacterial infections. It is well known that a particular problem with medical devices such as dental mini-implants is bacterial colonization. For this reason the use of nanoparticles coated mini-implants is a measure to prevent or to treat infections caused by microbial agents present in oral cavity. Our study considers the possibility of using silver doped hydroxyapatite thin films on titanium mini-implants as an osseo-integration and antibacterial component. Therefore several physic-chemical analyses were performed in order to determine their properties and to open new perspectives to develop nanoparticulated thin films as coatings for orthodontic mini-implants.

Keywords: orthodontic mini-implant, nanocoating, silver doped hydroxyapatite, osseo-integration, antibacterial properties.

In the last decade the manufacture of mini-implants used in orthodontic treatments led to a major change regarding therapeutic perspectives. The main advantages of dental mini-implants are represented by the insurance of a skeletal anchorage and by the facilitating of successful long-term orthodontic treatment [1-3].

The demand of orthodontic procedures by replacing a loss tooth with an implant increased in last few years for a big percent of worldwide people. Nowadays, researchers are looking for solutions to improve specific properties of these medical devices by coating their surface with nanoparticulate thin films which gives them a better osseo-integration and antimicrobial features [4-16]. A similar solution involves using cell-seeded scaffolds based on Adipose-derived Stem Cells [17, 18].

Titanium and its alloys are often used in orthodontic devices due to their good biocompatibility with bone tissue and high resistance to corrosion. A successfully long term of an orthodontic mini-implant depends on its osseo-integration with the surrounding tissue as much a sterile environment to limit the risk of microbial infections [19]. Similar infective processes were described also in the case of medical devices in which biofilms play an important role [20]. Osseo-integration implies various cells and tissues cooperation [21-25]. Though titanium and its alloys are almost ideal biomaterials, adequate results are not always guaranteed by their use. Orthodontic mini-implants are sometimes unpredictable because of incomplete osseo-integration thus increasing the risk to lose the applied medical device. Therefore additional investigations have to be done to improve host cell-mini-implant interaction for enhance osseo-integration process [26].

Unmodified titanium and its alloys are prone to bacterial infections which lead to inflammation and failure of the implant eventually. Once bacterial adhesion is prevented biofilm formation may be inhibited [26]. Hydroxyapatite with chemical formula $Ca_5(PO_4)_3OH$ is a bioactive and biocompatible material representing nearly 70% of inorganic component of bone matrix also known to constitute the mechanical strength of the bone tissue [27-31].

Some authors used the first time hydroxyapatite in clinical trials and that revealed an increased osseo-integration after 10 days post insertion of an implant [32]. Furthermore, hydroxyapatite has been used in-vivo studies on animals as coatings for medical devices to study the efficiency regarding the stability and interaction with surrounding bone tissue. Interactions between hydroxyapatite coated implant and bone tissue is due to the biomimetic features of hydroxyapatite such as grain structure, mechanical and surface properties [21-34]. Another issue regarding failure of an orthodontic implant is the result of bacterial infections. Silver is known to be used in medicine to serve as an antimicrobial agent. Due to this property silver is considered a medical coating with antimicrobial activity that includes binding to bacterial DNA thus preventing bacteria replication [35-43].

The aim of this work was to obtain an orthodontic mini-implant coated with silver doped hydroxyapatite with antimicrobial properties and osseo-integration of as coated mini-implant with bone tissue respectively.

Experimental part

Materials and methods

Several treatments can be applied on orthodontic mini-implants surface in order to enhance implant-bone tissue contact.

For this purpose we used a process representing a combination of ion beam sputter deposition and plasma based ion etching that produce a unique topography surface on the substrate with a thin film nanocoating which possesses adequate properties to stimulate osseo-integration and limit bacteria colonization.

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In case of ion beam sputter deposition the substrate is bombarded by energetic ions beam becoming from inside an ion source. In the discharge chamber gas atoms are ionized giving rice to a discharge plasma containing charged particles that are accelerated expelling thus the ions from the source at high velocity. The ion beam with negative electrons is counterbalanced by a neutralizer placed downstream from the ion source. Forwards, the ions impact the surface of the substrate producing particles to be ejected from the surface and sputtered on other surface within the vacuum chamber thus forming a thin film.

Plasma based ion etching starts by placing a substrate in a vacuum while the chamber is back-filled an argon type gas. Plasma discharge is produced by heating the gas thus causing its ionization. Thereby, the resulting plasma contains positive gas ions and negative electrons respectively. Next step consist in substrate immersing in the plasma under a negative voltage which attracts the excited ions causing them acceleration towards the substrate at high velocities. The ions hit the substrate and disrupt the surface structure at atomic level producing expelling of particles off the surface until they contact a different surface in the vacuum environment. This method creates a specific surface topography at micro- and nano-levels.

These two methods offer the possibility to design a surface coated with silver doped hydroxyapatite thin films to inhibit bacteria multiplication and to intensify the osseo-integration process.

EDS, SEM and XRD techniques were used in order to determine structural and morphological characteristics of silver doped hydroxyapatite thin films deposited on titanium substrate.

Results and discussions

EDS spectra evaluation of etched titanium substrate coated with silver doped hydroxyapatite was used to determine weight percentage (wt%) of silver in the hydroxyapatite thin film revealing quantitative results of samples as shown in figure 1. First test group of substrate contains a lower silver concentration (S1) and the second test group contains a higher silver concentration (S2) in the hydroxyapatite thin film. Average values of the samples revealed that S1 sample had a silver concentration of 0.64 ± 0.28 wt% and S2 sample had a higher silver concentration of 1.52 ± 0.34 wt%.

Quantitative results of the substrates annealed in air revealed that silver concentration in hydroxyapatite thin films remained the same after thermal heating as shown in figure 2.

From SEM images of S1 and S2 samples (shown in figure 3) it can be seen that small cracks were formed in hydroxyapatite film after thermal treatment. This may be possible due to residual stresses in hydroxyapatite thin film during annealing or to variations in thermal expansion between implant surface and hydroxyapatite thin film.

XRD patterns of annealed S1 and S2 samples with low content and high content respectively of silver in hydroxyapatite thin films (fig. 4 and fig. 5) displays peaks corresponding to hydroxyapatite and silver.

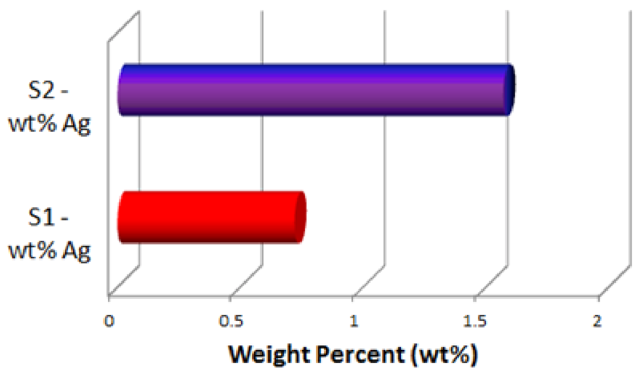

Fig. 1. Weight percent (wt%) of silver doped hydroxyapatite thin films

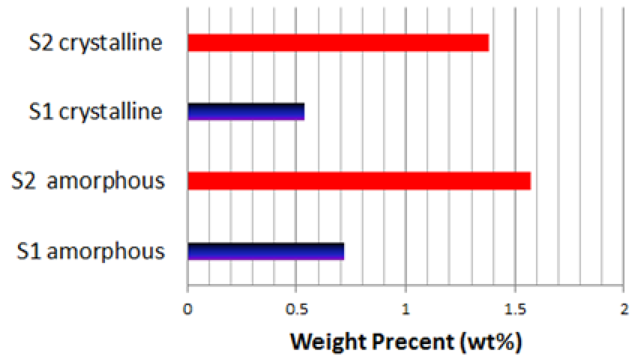

Fig. 2. Weight percent (wt%) of amorphous and crystalline silver doped hydroxyapatite thin films before and after air annealing

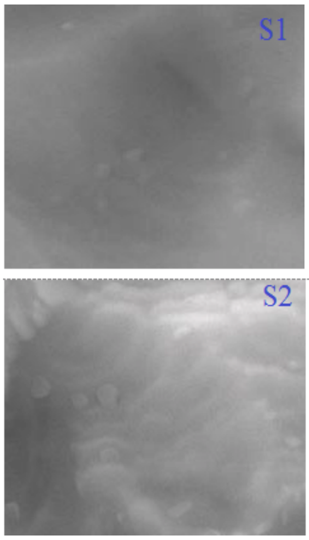

Fig. 3. SEM images of S1 and S2 samples on etched Ti (25000X)

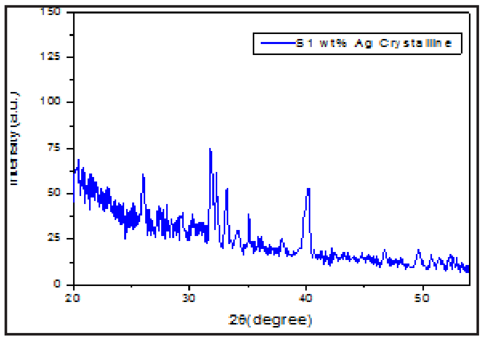

Fig. 4. XRD pattern of annealed 0.5 wt % silver doped hydroxyapatite thin film

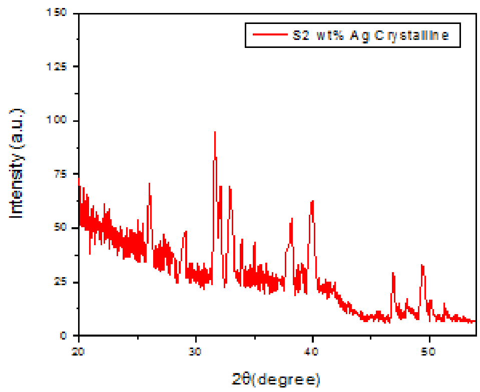

Fig. 5. XRD pattern of annealed 1.5 wt % silver doped hydroxyapatite thin film

From XRD spectra it can be observed that hydroxyapatite peaks are significant although is not clear that hydroxyapatite is totally crystalline. Even so, these peaks ensure that thin films have undergone a high amount of re-crystallization.

Conclusions

This work revealed the importance of modifying the surface of dental mini-implants by coating it with different nanoparticles for enhancing osseo-integration and preventing biofilm formation respectively. Nanoparticles deposition on titanium surface of mini-implants offers the possibility design structural and morphological features on nanoscale that has been shown the advantages both for cell proliferation and preventing the infections caused by pathogenic microbial agents. Advanced techniques for these thin films characterization revealed the possibility to control the amount of silver doped on hydroxyapatite films and thus to obtain the uniform distribution of silver on entire surface of thin films. Thermal treatment consisting of annealing in air proved to increase thin films stability in dry or aqueous environment.

As new perspectives on this issue include developing of medical devices coated with nanoparticulate thin films having benefits in operating room. This needs more studies on physical and chemical forces that relate to a greater stability of thin films in cell culture media. Further tests should be done to investigate the behavior of Gram-positive and gram-negative pathogens that affects dental implants in order to perform biological characterization of silver doped hydroxyapatite thin films.

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