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Bioactive coatings on the Ti-6Al-4V alloy for biomedical application: a brief review

Robert Saraiva Matos[1,2] and Erveton Pinheiro Pinto[2]

[1]*Biomaterials Laboratory, P²CEM/DCEM/UFS/UFS, São Cristovão, SE, Brazil,*

[2]*Amazonian Materials Group, Physics Department, Federal University of Amapá, Macapá, AP, Brazil,*

Abstract: In order to obtain bioactivity in bone implants many biomaterials have been tested and often many of them have shown excellent results. In this regard, it is important that the biomaterial be considered safe and carry mechanical and biological properties that can make them functional. Among the most used bioactive materials for a better integration of the implant with the bone stands out Hydroxyapatite and Chitosan which are widely used biomaterials. This paper presents a review of the most commonly used bioactive coatings on Ti-6Al-4V alloy, which has been the most recommended alloy for implants today. Theoretical aspects addressed in various studies conducted in recent years were taken into consideration. The results show that this alloy has functioned as a promising substrate for implant development, with the improvement of important characteristics such as surface adhesion, corrosion and bioactivity.

Keywords: Biomaterial; Ti-6Al-4V; Hydroxyapatite; Chitosan; Adhesion; Corrosion; Bioactivity.

I. INTRODUCTION

It is undeniable that the improvement in quality and life expectancy has increased in recent decades, with the advent of technology that applied medicine has improved processes that help people and develop resistance to disease. Canvas technology is associated with many materials that have been developed for use in the field of biomedicine, for example. Currently, many of them being polymeric, metallic, ceramic or composites are related to biomedical applications.

Diseases linked to bone problems have disrupted the lives of millions of people around the world. Osteoporosis, the most common of them, is the object of study by many researchers because it causes irreparable damage to bone tissue, which has caused a significant difference in people's quality of life [1]. In this sense, the materials have played a relevant role, as studies have shown that some have biocompatibility with bone tissue and may serve as a bone substitute.

As time goes by, practices such as allograft, which always pose a danger because it can transmit infectious diseases [2], are disappearing and giving way to new techniques and materials that bring safer and more comfortable patients. bone diseases. In this perspective, biomaterials have had significant prominence in this medical follow-up.

In the 1960s, Professor Per-Ingvar Branemark first used titanium as an implantable material. At that time Branemark observed that titanium was incorporated into the bone tissue, and subsequently it was not possible to remove the coated bone mass around it without causing tissue damage. In this sense, Titanium emerged as a biocompatible material. From there the term Osseointegration arises to explain the fact that a material such as titanium becomes part of the individual's tissue and naturally replaces the bone matrix [3].

Since this period, many studies have been developed to alter the surface characteristics of Titanium or its alloys, so that osseointegration and biocompatibility processes are accelerated, reducing patient recovery time and improving implant performance [4]. In this sense, the physicochemical properties of the implant surface are fundamental to the success of the procedure, since they influence the biological responses. In addition, titanium meets three basic requirements for implant use: it is a strong, lightweight, and durable material.

In this sense, although it is more expensive to use titanium or its alloys over other materials such as stainless steel or Vitallium (60.6% Cobalt, 31.5% Chromium and 6% Molybdenum and the remaining <1 % Si, Mn and C) and at a lower cost and are more used in the Unified Health System (SUS), titanium is safer. In addition, these two materials have a predetermined shelf life, which always forces a new surgical procedure on the patient and usually causes a new trauma, which will be costed again by the system, thus generating more burdens [5]. In this sense, other materials generally produce twice as much expense for the state than the use of a safer biomaterial such as titanium.

Therefore, a lot of study is important for the biomaterial to be considered safe, since the study of the superficial characteristics of the implant takes into consideration the topography, surface load, and mobility [6], because it is in the tissue implant interface that occurs protein adsorption, cell surface interaction and cellular development of the tissue at the interface. In this sense, Ti-6Al-4V alloy has been highly recommended for implants because it has a low modulus of elasticity and biocompatibility over other commercially available alloys.

Although Ti-6Al-4V is biocompatible with excellent mechanical properties, there are still some problems that have been described in the literature. Corrosion [5] of the alloy and slow patient recovery in complex procedures [4] are common problems that affect the use of these biomaterials without proper surface treatment. Thus, what is constantly sought is a biomaterial that can expedite bone contact during the healing phase so that the osseointegration process is optimized [7].

Thus, it is important to mention that the more biocompatible the biomaterial is, the better the individual's response to the implant and the faster its recovery [8]. Considering that there are still doubts about the physical properties of the Ti-6Al-4V alloy, the engineering of materials has been working to develop superficial treatments in this alloy that integrate compounds that are already part of the bone matrix, especially, those that carry calcium phosphate and receptor-ligand-like structures. This may lead to better performance in material biofixation [7], which may lower costs and improve patient comfort, as there will be more reliability and fewer implant failures.

The chemical composition and morphology of the implant surface are critical in determining how bone-implant interface reactions will occur. The increase in calcified matrix deposition and the velocity of the deposition, leading to a modification of the surface topography, with consequent increase of the surface roughness, has been considered supporting in the process of improving the biocompatibility aspects of the materials [9]. Thus, rapid bone response and strength at the bone-implant interface has been observed with the treatment of implant surfaces, including dense patterned tissue growth perpendicular to the rough surface of the implant [10].

In order to support the surface modification of titanium or its alloys, it is necessary to integrate compounds that have structures capable of rapidly integrating the implant with bone. These compounds can be found at once in a calcium phosphate-based composite, which is the fundamental component of the bone matrix and some other polymeric compound of the order mucopolysaccharides, which also naturally integrates the bone. The most complex phase of this process is the deposition of this composite on the surface of titanium or its alloys, although some methods that allow this application are already known, among which Electrodeposition, Sol-Gel and Biomimetic stand out.

This ceramic-polymer composite should provide, among other characteristics, the formation of scaffolds that can help to improve the interaction of the implant with the bone. The advantage of using biodegradable polymers for composites is that they simulate the cellular environment. In addition, they have a porous matrix; has biocompatibility in absorption rate; It has a high performance for cell adhesion, proliferation and differentiation and has similar mechanical properties to the receptor site [11].

This combination may lead to improved performance with respect to corrosion resistance and biological response, which are the key features to be improved in titanium-based implants today, assuming that the bioactive coating behaves as a facilitator of biofixation and bioactivity. -bone-implant life. Thus, the aim of this study is to present a review of bioactive coatings on Ti-6Al-4V alloy to biomedical biomaterials.

II. THEORICAL CONTEXT

2.1.Biomaterials

There are several definitions used in the scientific world to define a biomaterial, but the classic one says that when a material restores, enlarges or replaces some organ, tissue or some function of the human body, then it will be called biomaterial, protected of course its biocompatibility. [12], as mentioned above.

Metals have been the main materials with applications in the medical field, especially in the bony part of the human body, where applications are diverse, such as wires, screws, fracture fixation plates, prostheses [13]. Many metals have been adapted to the implant area, namely: Fe, Cr, Co, Ni, Ti, Ta, Mo and W, as well as various alloys of these metals [14].

Already the bioceramics are, historically, most used in the dental area. Resins for restoring perforated teeth, crowns and dentures, as well as their use as a coating on metal substrates for biomedical application, are some examples. They are, from a biological point of view, better accepted than polymers and metals and are inserted in the context of partial bone replacement and organ support, as they have high hardness and wear resistance [14].

Polymers, in turn, have many products widely used in the medical field. Examples are face prosthetics, contact lens acrylic resins, tracheal tubes, artificial transplant organs such as artificial hearts or pacemakers, artificial tendons (such as polymers such as polyethylene, polyester and silicone, which present low mechanical resistance, good elasticity, low density and optimal processing) [13].

Innovation in the development of implantable materials is increasingly tending to stimulate multicomponent systems such as composites, which are the joining of metals, ceramics and polymers, so that the characteristics meet the requirements of body-adaptive material. hu-mano [15].

2.2.Ti-6Al-4V Alloy

Ti-6Al-4V alloy is widely used in the field of orthodontics and orthopedics due to its machining performance and workability. In addition, this alloy has high corrosion resistance and bioinert activity, which is what implant production requires. Implant surfaces require surface properties that allow noninvasive interaction of tissue with the alloy. In this sense, surface energy and roughness influence cellular responses in the short, medium and long term and will determine if the alloy is useful, which is the case of Ti-6Al-4V alloy [16].

Several heat treatment modifications have been made to this alloy over time to improve mechanical properties such as high tensile strength (>1000 MPa) [17], high yield strength (>900 MPa) [18] and low ductility (total elongation <8%) [19].

On the other hand, this alloy also has lower density, besides its two-phase microstructure, compared to pure titanium, being the α hexagonal phase with aluminum in solid solution and the β phase with vanadium stabilizing the cubic lattice. of centered body, which helps in better mechanical resistance [20].

These facts, associated with the low modulus of elasticity (112 GPa) compared to stainless steel (210 GPa), which is still the most commonly used implant material in Brazil, and the osseointegration of titanium, make Ti-6Al-4V a more useful biomaterial, although until recently almost all titanium alloys were imported, which made the implant process using these alloys economically unviable [21] compared to stainless steel.

However, titanium and its alloys do not chemically interact with bone tissue, which limits the limited use of these biomaterials, as the most delicate implant processes occur in post-implants and involve inflammation, healing, and late wear. Thus, it is necessary that the implant surface can reliably interact with the cells in such a way that not only osseointegration occurs, but rapid tissue recovery [22].

For this to happen many studies have reported that hydroxyapatite, being a calcium phosphate present in human bone, has helped to improve the processes of bone cell formation and proliferation at the bone implant interface. In this context, Ti-6Al-4V alloy surface hydroxyapatite coatings have shown better results than those without any treatment, as in the studies historically reported by [23].

2.3. Hydroxyapatite

Ceramics are hard but fragile materials and their use associated with medical implants have been restricted to bioceramics, which are currently studied and useful biomaterials [14]. In this sense, calcium phosphates have been given special attention because they are one of the essential components of human bone and much research seeks to improve the synthesis processes of these biomaterials. There are many techniques for obtaining calcium phosphates, which are related to precipitation in aqueous solutions, solid state reactions, hydrothermal methods, sol-gel process and, more recently, microemulsion [14].

Among the most biocompatible bioceramics that exist, hydroxyapatite $Ca_{10}(PO_4)_6OH_2$ (HA) has been highlighted by the large volume of studies, since it is very similar to bone and dental components. HA is used as a coating on metallic implants, usually made of titanium or its alloys [14]. For this, we seek to improve the surface characteristics of the implants, joining the mechanical resistance of the metal to the biological activity of HA.

Hydroxyapatite has hexagonal crystalline structure, with lattice parameter: a = b = 0,943 nm and c = 0,688 nm [24]. The atomic arrangement of hydroxyapatite has two crystallographically independent calcium atoms. In the basal plane there are OH^- ions, which are positioned at the vertices and occur at equidistant intervals along the column perpendicular to the basal plane and parallel to the C axis.

Since biological hydroxyapatite is very difficult to obtain, it is common to observe the use of synthetic coating of titanium alloys for implant applications [26]. Many works related to the characterization of the biological calcium phosphate present in the bone interface explain that it is composed of apatite monocrysts, which is different from synthetic HA in both composition and structure. Synthetic HA has a low crystallinity and is very calcium deficient; biological HA has a higher calcium concentration [13, 14].

Despite the advantages of calcium phosphates, in particular HA, some studies have reported that Ti-6Al-4V alloy surface treatments with hydroxyapatite have not shown satisfactory proliferation, growth and adhesion results when compared to surface treatments. in this alloy with HA/Chitosan composites, since the combination of the mineral with the receptor-ligand structures of the biopolymer provides a favorable environment for this fact. In this sense, the use of biopolymers has been shown as an alternative to improve the performance of these calcium phosphate coatings [27, 28].

2.4. Biopolymer: Chitosan

As is known, biopolymers can be homopolymers or copolymers from sources of organic matter and are therefore biodegradable, which pleases environmentalists [29]. The best explanation for the search for biodegradable materials for the medical field is associated with the structures that compose them, among which are the receptor-ligand mechanisms that most often facilitate the biological interaction of the material with living tissue.

Chitosan belongs to the class of polysaccharides, which are natural biopolymers, and are excellent hydrogel builders, where the type of monosaccharide and the nature of the substituent groups are fundamental to its formation. In this sense, the formation of a polysaccharide gel such as Chitosan is governed by two specific bonds, namely, hydrogen and ionic bridges [30]. This gel formation allows the easy use of biopolymers in the formulation of composites using the correct technique.

On the other hand, the extracellular matrix, which in the case of bone is composed of protein networks and locally secreted polysaccharides, is mainly composed of mucopolysaccharides. Mucopolysaccharides or glycosaminoglycans (GAGs) may aid the process of circulating nutrients and hormones as well as other chemical messengers in the bone matrix [30].

In addition, Chitosan is a chitin deacetylation-derived polymer found in arthropod skeleton with excellent biodegradability, antibacterial and hemostasis properties [32]. It is a semicrystalline biopolymer, and its crystallinity is associated with the degree of deacetylation and its minimum crystallinity occurs at intermediate degrees of deacetylation [30].

The degree of crystallinity influences the solubility properties. Thus, depending on the degree of solubility, Chitosan offers different processing possibilities. Thus mechanical properties are also affected by this buoyancy of solubility [33] which makes Chitosan a widely studied biopolymer for the formation of hydroxyapatite composites for Ti alloy coatings Ti-6Al-4V as well as others.

2.5. Composite Coatings

Recent studies with apatite carbon fiber composite coatings [34] and collagen calcium phosphate [35] are examples of composite materials that revealed important results for biomedical applications in orthodontics and orthopedics.

The issue of improving features such as biocompatibility, biodegradability and mechanical properties make composite coatings the most sought after materials recently. A composite coated material for bone tissue regeneration has to induce the production of new tissue cells for recompositing without abnormalities [36].

Thus, composite coatings, which are characterized by two or more different phases, have proven to be excellent multiphase and anisotropic materials that impart better physical, chemical and biological properties than one phase alone. What differentiates a composite coating from a single phase or structure coated material is that some properties can be improved [37].

In order to obtain a good composite coating, some conditions of the dispersed phase must be observed, such as: geometry, concentration, distribution and orientation. The way in which the composite is processed is perhaps the most complex step of the process [38], considering that they are different materials whose reaction is not so predictable, although the characterization is well served with the various available techniques.

2.6 Methods of Obtaining Coverings

Many studies have worked mainly on the combination of calcium phosphates such as HA with metals, so that there is at the same time mechanical resistance and quick connection between implant and biomaterial. The production of HA-incorporated polymer composites or biopolymers for coating of implant-relevant metal biomaterials is relatively new and it all depends on how this coating is made. The most commonly used methods for deposition of the most effective ceramic-copolymer composites are Sol-Gel, Electrochemical and Biomimetic Method [39].

2.6.1 Sol Gel Method

In Sol Gel, the inorganic material must be prepared with metal solutions with the alkoxide group, but other organic and inorganic salts can also be used, which is important to ensure the source of cations. After that, water for hydrolysis and alcohols as solvents are added.

The result is that the solution turns into a sol. Subsequently, the reactions proceed, interconnecting the particles almost static, so that the sun becomes a gel. Figure 1 shows a schematic representation of the sol gel process. After drying the gels may already be the end products or they must be calcined or sintered to obtain fibers, powders, ceramic coatings or monoliths [40].

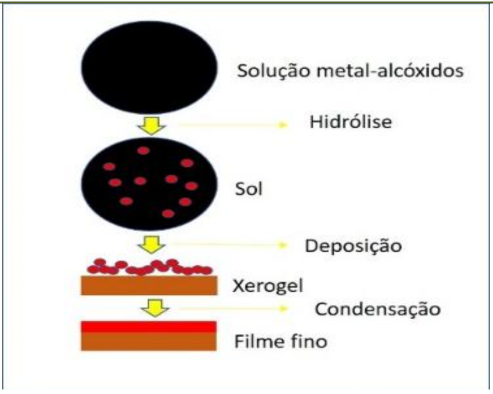

Figure 1. Schematic representation of the Sol Gel method.

The best part of using this method for the production of thin films is that the processing temperatures are low, the coating can be mechanical or automated, it is possible to obtain films with thicknesses ranging from 10 Aº to a few mm. For the Sol-Gel method techniques such as Dip Coating, Spin Coating are the most used [14].

In the Dip Coating or Dip Coating technique, the substrates are immersed in the sol until the coating becomes consistent. In Spin Coanting deposition, the sun is placed on the rotating substrate until the coating becomes consistent [41].

2.6.2 Electrodeposition

The electrochemical method, in particular that of Electrodeposition, is a technique most commonly used for deposition of metallic films on metallic surfaces such as those in gold-plated brass rings in the formation of semi-jewels. However, similar to this one, it has been used for the deposition of ceramic films, especially calcium phosphate, on metallic surfaces of importance to the implant area, based on the cathodic reduction of water. This reaction provides an increase in pH in the vicinity of the cathode-acting electrode that helps precipitate Ca_{2+} and PO_4^{3-} ions, so that an insoluble and adherent layer settle on the cathode [40].

With this technique it is possible to produce calcium phosphate coatings on Ti substrates with carbonate apatite-like structure. In this case the electrolyte is an aqueous solution of $CaCl_2$ and $NH_4H_2PO_4$. The technique works in two ways: applying a constant potential or constant current. What is sought with this technique is to provide more uniform coating growth, as [42] PILLIAR (1993) argues. Thereafter, the density and adhesion of the coating can be improved by vacuum sintering at low temperatures.

In 1997, a coating of HA on Ti substrate by electrodeposition at 62ºC for 20 min, with a NaCl, $CaCl_2$, K_2HPO_4 electrolyte at pH 7.2, with a cathodic current density of 160 $mA.cm^{-2}$ was obtained. Ban et al. [43]. Additionally, in vivo tests were also performed on rabbit femur, which found increased compressive tensile strength in coated implants than uncoated implants after 3 weeks.

Obtaining electrodeposition coated substrates, although financially accessible, has some disadvantages, such as: the thickness of the coating is limited due to increased strength of the vat; HA adhesion is affected by the release of hydrogen on the cathode due to the electrolytic reaction; low rate of formation and adhesion of the layer to the substrate [44].

2.6.3 Biomimetic Method

As is well known, there is a differentiation between biological and synthetic hydroxyapatite since the former has lower crystallinity and accommodates different types of ions in its structure due to ionic substitutions in its network. This directly influences its biological function [14]. Therefore in 1990 a method was developed by Abe and collaboratorsthat makes it possible to coat any substrate with hydroxyapatite, whose composition is closest to the biological apatite evenly up to 15 mm thick [45].

In this method the substrate to be coated is placed in a solution that simulates the inorganic part of the Simulated Body Fluid (SBF) with ionic composition similar to blood plasma. At the same time a bioactive G glass with a controlled composition for (%) MgO; SiO_2; P_2O_5; $CaF_2$is placed at a limit distance of 5 mm from the substrate and this configuration is kept for a few days at room temperature, where a thin layer of biological HA crystallites is formed. The thickness of the layer may be increased if the fluid concentration is increased. ABE et al. [46] explained that this is due to the fact that the silicate ions present in the glass dissolve and adsorb on the substrates. After that, HA nucleation occurs over the silicate ions, where the nuclei grow due to SBF. This method is known as Biomimetic [14].

III. LITERATURE ANALYSIS

3.1. Bioactive Hydroxyapatite Coatings

Ti-6Al-4V Alloy is the most studied alloy today due to its strength and high performance as well as its low cost compared to other alloy types. Benea et al. [47] compared this untreated alloy with that treated with nanoporous Titanium. The substrate was further coated with electrodeposition hydroxyapatite. A 2.5 x 2.5cm electrode was used. Anodizing of Ti-6Al-4V plates occurred at a constant voltage of 100 V for 2 min. Fig. 5 shows. Prior to hydroxyapatite deposition an alkaline treatment was performed to provide a layer of Sodium Titanite to induce apatite growth. Electrodeposition occurred at room temperature, whose electrolyte composition was 0.042 mol. $L^{-1}Ca(NO_3)_2$, 0.025 mol.L^{-1} $NH_4.H_2PO_4$ and 0.1 mol.L^{-1} $NaNO_3$ with a pH = 4.2.

This work shows the surface difference between Ti-6Al-4V treated with nanoporous Titanium and the obtained hydroxyapatite coating. For the alloy treated with Titania nanoporous was observed a roughness of 123.35 nm and the coated with hydroxyapatite was observeda roughness of 79.57 nm. This process is attributed to the fact that hydroxyapatite forms a thin film over the alloy generating a smaller rough profile than in the alloy treated with nanoporous Titanium, as in Benea et al. [47] and Benea et al. [48]. This result indicates that the sample with nanoporous Titanium may induce better cell adhesion since roughness is associated with adhesiveness.

In addition, it has been found that the coating with nanoporous Titanium has a higher corrosion resistance performance than hydroxyapatite coated alloy in the presence of salivary liquid. This behavior is due to the surface's ability to retain the salivary liquid with the hydroxyapatite coating, which does not occur for the alloy treated without the coating. In a similar experiment, Benea et al. [49] also attribute this corrosion resistance behavior to low coefficients of friction attributed to nanoporous Titanium treated alloy. Benea et al. [47] also attributes the difference to the wettability attributed to the hydroxyapatite coating.

Still in this sense, Popa et al. [50] showed that Ti-6Al-4V alloy improves cell adhesion properties at the bone implant interface when coated with hydroxyapatite compared to pure titanium. In that study, SEM images showed that the surface morphology became denser, where the observed pore diameter was ~ 1µm, which is considered a structure to promote cell adhesion when the coatings were immersed in physiological fluid. After that, now by immersion, it was contacted that as the immersion time increases the morphology changes with increasing roughness. In this sense, electroplating proves to be a very effective method for the coating of this alloy, promoting even an improvement in corrosion resistance properties.

Wang *et al.* [51], prepared and deposited hydroxyapatite films on Ti-6Al-4V alloy by the Sol Gel method and found that the films had high crystallinity, whose Ca/P ratio was slightly higher (1.75) that the theoretical value (1.67) is defined for HA with the loss of the porous element. In addition, the surface morphology observed in SEM showed that the surface texture changes while the pores shrink. The authors argue that as an implant this biomaterial may increase interlock at the implant-bone interface.

Fatehi*et al.* [52] were able to produce hydroxyapatite coatings on Ti-6Al-4V alloy by the Biomimetic ethod, y stimulating apatite growth by inserting 0, 5 and 10 M saline solution into SBF. They concluded that there was formation of biological hydroxyapatite that varied as the saline concentration. In addition, it has been observed that this combination improves cell adhesion properties, and consequently improves implant-bone binding. Thus, Ti-6Al-4V Alloy can act as a bone substitute, provided that there is adequate treatment on its surface so that it can create a favorable environment for cell proliferation and adhesion associated with biocompatibility and mechanical properties of the alloy.

In addition to the above reports, it is important to mention that proper treatment of Ti-6Al-4V alloy can improve the bonding process of composites on the alloy, as hydroxyapatite may detach from implant over time. It was what it sought to do, Miranda et al. [53], who underwent surface treatment on the alloy before undergoing Hydroxyapatite deposition. In the study, a laser machining process was applied to the alloy and it was demonstrated that a undegraded HA volume reached satisfactory indices. In this sense, it is proven that it is possible to improve implant surface characteristics with a good surface treatment of the alloy.

Using the hot-pressing technique, Buciumeanu et al. [54] studied the tribocorrosion of the Ti-6Al-4V alloy reinforced with hydroxyapatite coating (5-15%) using artificial saliva. According to the authors, hydroxyapatite acts in the tribocorrosion process increasing the wear resistance, thus improving the behavior of the uncoated alloy. Thus, the authors conclude that bi-composite materials can confer better tribological behaviors in the alloy than without proper treatment. In this respect, it is clear that Ti-6Al-4V alloy composite coatings provide better mechanical and biological responses in implants than the use of an implant without any surface treatment.

Still using the plasma spray method, Levingstone et al. [55], developed Hydroxyapatite coatings on Ti-6Al-4V substrates, demonstrating that the crystallinity of the coating depends on the deposition process. This means that depending on the thermodynamic process variables the coating may have its physical characteristics affected.

One of the major problems with Hydroxyapatite (HA) is the poor bonding that prevents good adhesion of ceramics to metal. In this sense, ZHENG et al.[56], produced HA/Ti composites and, using the plasma spray method, produced HA/Ti coatings on Ti-6Al-4V alloy and showed that there was an improvement in the adhesiveness of coating. Also, in the same experiment, Scanning Electron Microscopy revealed that the apatite distribution on the composite was not affected by the addition of Ti. This shows that metal-ceramic composites can improve surface adhesion mechanisms.

In vivo tests are important to analyze the behavior of the implanted material in order to study the viability and applicability. In this sense, Li et al. [57] using a material derived from a mixture of titanium alloy (Ti-6A1-4V) and calcium phosphate, implanted intramuscularly and orthopedically in 10 goats. After that he evaluated the new bone composition, where it was found that there was formation of ectopic bone tissue, which is similar to mature or lamellar bone tissue for the study with goat bone marrow stromal cells. The study concludes that these results identify that titanium mixed with calcium phosphate behaves better than when used alone.

4. Ceramic-Polymer Bioactive Coatings

On the other hand, the use of biopolymer to obtain ceramic-polymeric coatings has been an excellent alternative for surface optimization of titanium alloys. In this sense, Raj and Mumjitha [58] produced an electrodeposition Chitosan (CS) - Polyvinylpyrrolidone (PVP) - Hydroxyapatite (HA) coating on Ti-6Al-4V alloy and found that the composite coating improves hardness and adhesion compared to surfaces coated with hydroxyapatite alone or to individual polymers. In addition, the coating showed better corrosion resistance with a slight saturation for the 4% and 6% PVP samples, with good cell adhesion, especially for PVP composite samples. and low cytotoxic performance.

Tang et al.[31] showed that the composite of carbonated HA and chitosan deposited by electrodeposition in Ti-6Al-4V alloy has a moderately hydrophilic character, with a contact angle of 29.4º due to chitosan. In addition, bone cells were used in in vitro tests and it was observed that the coated surface promoted cell adhesion, spreading and proliferation in HAcarbonated/Chitosan coatings more effectively than with pure hydroxyapatite. This suggests that the improvement in biocompatibility is due to the way the composite is prepared, considering that it must meet the organic and inorganic characteristics present in the bone, when the application is for implants.

It is evident that due to its good bioactivity hydroxyapatite has been extensively studied for coatings, but its fragility is a major impediment. In this sense, GOPI et al. [59] developed an electrodeposition composite coating of mineralized HA and Chitosan on Ti-6Al-4V alloy to improve mechanical and biological properties. The SEM images differentiated the results obtained in that the treated alloy presented a higher roughness than if no treatment and found that the composite behaved satisfactorily with improved adhesion and cell proliferation. This is explained by the fact that the more crystalline hydroxyapatite the better its adhesion performance because the higher crystallinity promotes greater surface roughness.

Attempting to obtain a dielectric and biochemical response of a coating of polylactic(PLA) and polyglycolic acid (PGA), hydroxyapatite, chitosan and collagen on Ti-6Al-4V alloy, Supelano et al. [60] have shown that at the interface between PLA-PGA-HA/Chitosan coating and osteoblastic cells there is a higher adsorption of biomolecules compared to PLA-PGA-HA coating, which occurs by diffusion. In addition, the electrolytic circuit model adjusted for the experiment allowed us to clarify that the PLA-PGA-HA/Collagen coating has higher capacitance compared to the others, with PLA-PGA-HA/Chitosan being the intermediate. This even shows that composite coatings may have better corrosion resistance performance, which is a result similar to that found by [47] than coatings containing only hydroxyapatite.

On the other hand, thinking about reducing the risks of infections associated with medical implants, Yanovska et al. [61] developed a composite of Silver, Chitosan and Hydroxyapatite nanoparticles. In the experiment the Ti-6Al-4V alloy substrate was modified by the deposition of a chitosan film, whose wettability is affected depending on the composition of the film [62], and then the composite prepared by the sol gel method was deposited on this surface. By atomic absorption it was possible to detect a large amount of silver particles in the composite coating. In addition, antibacterial activity was verified in the coatings against *Escherichiacoli*. This fact is explained, according to the authors, by inhibition of bacterial adhesins by released Ag + ions and this inhibition resulted in a 21% decrease in bacterial adhesion.

On the other hand, using two alloys of different elastic moduli, such as Ti-6Al-4V and a new Ti-Zr-Nb alloy, which has an elastic modulus of approximately 50 GPa, Pylypchuk et al. [63], using the Biomimetic method, obtained two hydroxyapatite-coated biomaterials. The authors found by XRD that the thermal conditions of the method affect the size and formation of HA crystals. Also, in this regard, SEM images confirmed that the deposited HA had different morphologies on the two substrates and the photoelectron spectroscopy also showed that the Ca/P ratio were different for the two alloys, namely: 0.97 and 1.15, respectively. This fact shows that although there is a difference in this ratio 0.97 is an excellent value considering the cost benefit of Ti-6Al-4V alloy. Thus, it is clear that much work can still be done with hydroxyapatite composites and biopolymers that appear to show more promising results for Ti-6Al-4V alloy coatings.

IV. CONCLUSION

From the survey made it is possible to see that Ti-6Al-4V is an excellent substrate for bioactive coatings, considering that in all cases analyzed, the coatings or treatments on its surface showed a biomedical application. plausible. The improvement in the adhesiveness of osteoblastic cells on the surface of the composites stands out; the anticorrosive barrier generated mainly by the hydroxyapatite coating; the acceleration of biological interaction processes at the bone coating interface and the optimization of the bonding processes between the alloy and the coatings. Moreover, it is noted that the influence of the coating method does not seem to affect the application of the coating on the alloy, since in all cases discussed there was improvement in surface characteristics and biological interaction in in vitro evaluations. In this sense, this survey shows that Ti-6Al-4V alloy is a promising substrate for the development of biomaterials that can attribute greater functionality in the processing of biomedical implants.

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