Journal of Composites and Compounds 2 (2020) 26-34

Available online at www.jourcc.com

Journal homepage: www.JOURCC.com

Journal of Composites and Compounds

Hydroxyapatite consolidated by zirconia: Applications for dental implant

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A B S T R A C T

Zirconia has garnered significant attention as a new ceramic material for dental implant due to its excellent biocompatibility, strength, and promoting the oral rehabilitation with high aesthetic, biological and mechanical properties. It also expedites the amelioration of bone minerals surface by its bio-integrative ingredients which are naturally close to ceramic intrinsic of bone. Alternatively, hydroxyapatite (HAp) has prevalently been used in dental implant due to its high biocompatibility. However, it generally shows weak strength and mechanical properties. Consequently, incorporating zirconia and HAp produces appropriate composites for dental implant having improved physiochemical properties. This review provides discussions addressing the methodologies and exemplars for the designed composites used in dental implant applications. The representative methods for surface modification of zirconia incorporating HAp (i.e. sol-gel, hot isostatic pressing, plasma spraying, electrophoretic deposition, etc.) is highlighted. The advantages, disadvantages, biocompatibility, strength, and osseointergration and biointegration properties of the presented composites are explored.

A R T I C L E I N F O R M A T I O N

Article history:
Received 25 November 2019
Received in revised form 02 January 2020
Accepted 27 February 2020

Keywords:
Hydroxyapatite
Zirconia
Dental implant
Biocompatibility
Coating
Ceramic composite

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1. Introduction

Dental composites have been confirmed as safe component for filling rotted teeth, principally because of their superior aesthetics and biocompatibility [1-5]. They are typically composed of resin matrix and inorganic fillers [6-8]. Although considerable investigations have been carried out to improve the monomer structures and filler formulations, secondary caries and rebuild fractures of dental composites are the major reasons to repair failure. The accessible fillers cannot present expected strengthening and useful impact in dental composites. Thus, more endeavors have been made to produce fillers providing similar function and structure to the natural human teeth [9].

Recently various materials have been utilized in the field of hard

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DOR: 20.1001.1.26765837.2020.2.2.4.2
https://doi.org/10.29252/jcc.2.1.4

tissue engineering [10-12], e.g. hydroxyapatite (HAp) [13], bioactive glasses, bio-ceramics [14], bio-scaffolds [15, 16], etc. Among them, HAp has crystallographic and chemical similarity to human bone tissues, therefore, has extensively been utilized for bone-related issues. It contains calcium phosphate possessing chemical formula of $[Ca_{10}(PO_4)_6(OH)_2]$ [17-19].

In addition, HAp is very well-known biocompatible substitution for the essential mineral constituents of skeletal bones that can be utilized as orthopedic surgeries and tooth implant [20, 21]. HAp is considered to be extremely bioactive, osteoconductive, biocompatible, non-toxic, non-immunogenic, and non-inflammatory [22, 23]. The measurement of alkaline phosphatase activity has indicated that naturally isolated HAp can to be utilized for progression of both cell proliferation and differentiation [17]. Therefore, various chemical routes have been introduced for HAp synthesis including hydrothermal, sol-gel, mechano-chemical, precipitation, and polymer-assisted methods. HAp can also be fabricated from bio-waste or natural resources including clam shell [24], bovine [25], camel bones [26], corals [27], cuttlefish [28], and fish bone [17, 29].

It is noteworthy that the HAp coating application is one of the most promising surface modification method applied for dental implant. The HAp-coated implants have been widely utilized in dental applications due to their great biocompatibility with epithelium, and bone and connective tissues. A thin layer of HAp is used to coat the dental implant surface, which has been generally observed to be effective for the osseointegration process, load stress distribution, healing time to bone, bone implant contact, and bone crest repair [30]. Moreover, the HAp coating can improve the mechanical properties of the substrates; in particular, the surface biocompatibility and maintaining the load-bearing capacity. For example, the histology study and mechanical interface characteristics of HAp coated titanium and commercially pure (CP) titanium, revealed that the HAp coating enhances the mean interface stability of bead-blasted CP titanium system with no coating five to eight times [30]. HAp coated implant can also interact with the surrounding biologic environments. For dental materials, the importance of HAp coatings, due to their developed integration of osseous tissues, has been also improved for implant surfaces. These materials can play a role in the sources of phosphate and calcium in the enamel minerals in supersaturation state. Furthermore, they can protect the outer dental enamel caries lesion by mineralization system [30].

This review focuses on the effect of HAp incorporation either in the form of coating or composite incorporated zirconia. It discusses zirconia implant, nanocomposites, and surface modification techniques to enhance the bio-integration and osseointegration treatment of zirconia-based implant [31].

2. Dental implant

Implant dentistry is a prosthetic effort via a surgical procedure [32, 33]. In order to achieve an ideal prosthetic construct, precise plan should be taken into consideration prior to the beginning of treatment. The position of implant requires protected prosthesis. It can be affected by the implant size, volume, and the quantity and quality of bone provided at various sites [34].

Another parameter that requires to be integrated in to therapeutic deliberations is the measurement of accessible horizontal and vertical space for prosthesis adaption. Various reports have indicated the functional and aesthetic success of this therapy for up to six years of long-term follow-up [34]. In the field of dental implant, handful materials such as pure Ti and some of its alloys, zirconia, and tantalum have been found as appropriate implant materials up to now. The indication of osseointegrated implant in the bone is not closely discoverable mobility. Moreover, osseointegration should be protected during the lifetime of the implant owing to its effectiveness [31].

Biointegration has been described a sort of the interconnection between the recipient tissue and a biomaterial at the microscopic measurement. This connection among implant and tissue is a region of interaction or a specified boundary between the corresponding tissue and biomaterial [35]. Osseointegration is the presence of highly proximity between the supporting bone and the implant without including fibrous tissue or collagen. However, continuity of the implant to bone with no intervening space is known as biointegration. In fact, the ceramic-based implant chemical degradation should occur in the biointegration process for development of bone generation as well as integration of the ceramic implant around the bone. The nature or mechanism of both operations are not entirely understood so far, and their superiority over each other is not recognized very well. There is similarity between both interfaces are natural teeth clinical alkalosis. Although the ceramic has been coated on metallic implants primly enhance a bio-integrated interface, the interface stability is lower as a result of its degradation with time in long term [31] (Fig. 1).

In the past decades, the development of nanocomposites has opened new prospect in different fields to obtain materials with enhanced physical and mechanical properties [36, 37]. Because the nano-HAp has greater surface area and higher reactivity as a biomaterial compared with its bulk counterpart, it can provide significant characteristics in several medicinal fields, in particular, dental implant. The effect of HAp incorporation as coating materials in dental implants have been hopeful for

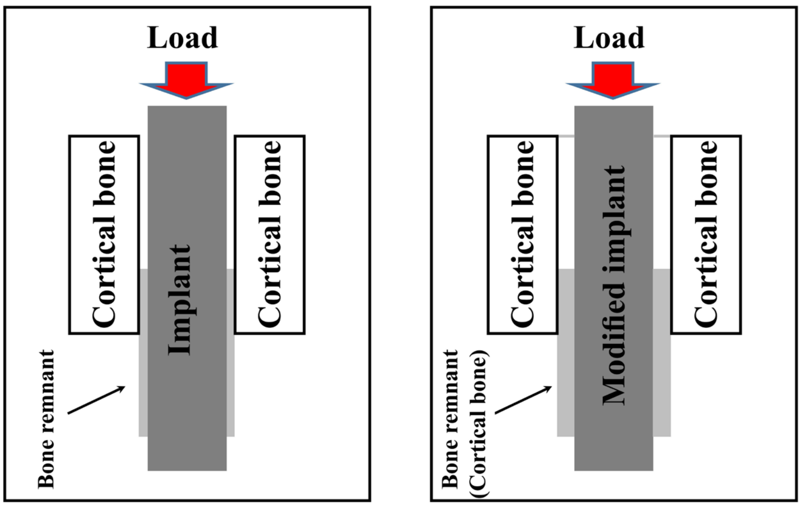

Fig. 1. Schematic illustration of implant vs. surface modified implant

futures applications. It can result in formation of chemical bond with bone and lead to reinforced biological and biointegration fixation [31].

3. Choosing an appropriate implant

Fabrication of dental implant is highly utilized with Titanium and titanium alloys due to corrosion resistance and high strength [38]. However, novel implant technologies are being improved, due to aesthetic compatibility and potential immunologic with titanium implant. Meanwhile, ZrO_2 implant is considered as an alternative to Ti-based implant in dental implantology. ZrO_2 has shown to be more effective as implant material [39, 40].

Zirconia (ZrO_2) is oxide form of a gray white, lustrous, strong transition metal named Zirconium (Zr) [41, 42], and has emerged as an alternative to common Titanium based implant for oral rehabilitation with higher aesthetic, biological, optical and mechanical properties [39]. In addition, Zirconia is very interesting because of its potential osseointegration and having other superior properties such as white color and translucency that mimics the natural teeth. It is radiopaque same as Ti and can be observed under radiography. Compared to Ti, bacterial colonization around ZrO_2 is seemed to be lower. Some investigates have indicated that zirconia has higher biocompatibility in comparison with Ti, as the latter fabricates corrosion products at the implant site [43].

Although many studies have been performed for titanium implant compared to zirconia in the past decades, high-strength zirconia ceramics have attracted a great attention as new materials for dental implant. This ceramic indicates minimal ion diffusion compared to metallic implants (i.e. Titanium), which mentioned to be inert in human body. Due to its biocompatibility, mechanical properties and tooth-like color, zirconia have become a superior dental implant material. Surface topography and material composition of a biomaterial in osseointegration act a fundamental role. One of the main agents in the surface of implant is their quality that effects healing of wounds at the implant placement and afterward influences osseointegration. Thus, different physical and chemical modifications of surfaces have been advanced to promote osseous healing [44].

The clinical application of zirconia dental implants is restricted owing to difficult modifications of surface. In addition, implant with smooth surfaces are disadvantageous for osseointegration due to weak tissues interaction [44]. Because bone consists of ceramic phase, a ceramic system with proper mechanical properties, which provides the mineral growth on its surface can be called the right biointegrative material. The zirconia implants with modified topography were investigated and their biointegration by laser modification, UV modification and methodologies like surface modifications were explored [45].

4. HAp-zirconia nanocomposite

Matsumoto et al. [46] studied a composite of HAp-incorporated zirconia having micro porous structure. Their results showed that the produced composite material possessed strength in the range of bio-cortical bone strength with high tissue and cell affinities by combining HAp and ZrO_2. It was found that by changing the molding pressure and raw materials particle size, control the quality of surface is feasible, proposing this material as a good candidate for bone restoration. Izquierdo et al. [47] deposited HAp /ZrO_2 composites on Ti-21Nb-15Ta-6Zr alloy through pulsed layer deposition and investigated their electrochemical properties. Results showed that the presentation of HAp/zirconia layers avoids the interaction of the biomaterial with active molecules and the subsequent reduction oxidation and enhances interaction between bone tissue and implant. The HAp–ZrO_2 coating modifies the Ti alloys electrochemical features in Ringer solutions. The prepared film had good bioactivity through generating an appetite layer similar to bone material and can be offered as a promising material for orthopedic and dental implants. The produced ZrO_2/HAp composite film indicates excellent surface roughness and energy and significant wettability compared to Zr substrate.

Bulut, et al. [48] investigated biocompatibility of HAp-zirconia and HAp-alumina composites and a ternary component of commercial inert glass. Results showed the great mechanical properties of the HAp-ZrO_2 composites as well as the development of bioactive properties. According to the obtained results, the ternary composites can be mentioned as promising materials for bone-related issues.

Buciumeanu et al. [35] deposited composite layers of bioactive zirconia on zirconia structures and investigated their tribological properties. The layer of bioactive zirconia composite (zirconia containing 10 vol. % of β-TCP or 10 vol. % of HAp) was successfully provided by press-sinter method on zirconia substrate. Their results showed that zirconia composites had a great potential to be utilized as a biomaterial in dental implants with a layer of the bioactive zirconia composite, due to great mechanical properties and developing bond between the implant and living tissue. The advantage of bioactive zirconia composite layer is that it is a suitable substitute to coatings on zirconia substrate due to decreasing the possibility of implant failure and the interfacial residual stresses.

Leong et al. [49] prepared nanocomposites of HAp/yttria stabilized zirconia (YSZ) under for dental materials. HAp/YSZ nanocomposites were obtained by wet ball milling and sintering pressureless and also under pressure using nitrogen gas. However, HAp decomposition was found to take place in the samples regardless of the sintering methods. In spite of the sintering techniques that investigated, relative density of 99.5% without identifiable HAp decomposition was attained only with the hot isostatic sintering technique.

Carvalho et al. [50] functionalized zirconia surface by HAp using hybrid laser method for applications in dentistry. Their results showed that the improvement of novel procedures for promotion of the implant biointegration and its long-term retention is challenging. The procedure attempts to mimic the natural bone material. By altering atmosphere and energy density, textured surface could be designed. Moreover, high volume of sintered and maintained bioactive material was produced when the process was carried out with low scan speed and high laser power.

Gergely et al. [51] studied microstructural and mechanical properties of ZrO_2/HAp nanocomposites obtained by spark plasma sintering (SPS). To prevent the reaction between ZrO_2 and nHAp and decomposition of nHA, the SPS method was carried out at short dwelling time (5 min) and low temperatures. It was shown that the mechanical and microstructural characteristics of the composites were strongly dependent on SPS technique specialties.

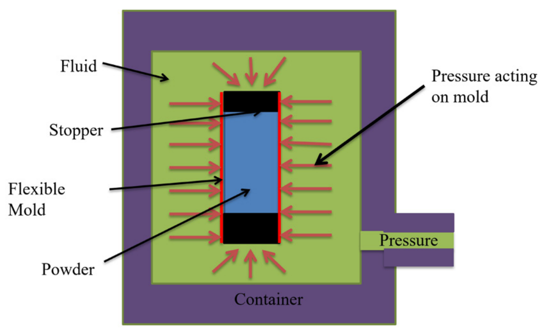

Fig. 2. Schematic of HIP method.

5. HAp-coated zirconia

Nowadays, many studies have focused on corrosion [52] and coating [53], especially importance of ceramic coatings as dental implant to enhance osseointegration. Different forms of ceramic coatings have been utilized on implants for dentistry over the last 15 years including inert ceramics such as zirconium and aluminum oxides and bioactive ceramics including bioglasses and calcium phosphates. Coatings can be porous or dense depending on their production procedure with a thickness ranging from 1 to 100 µm. Various ceramic coating methods in dental implants include sol-gel [54-56], hot isostatic pressing (HIP), plasma spraying [57-59], electrophoretic deposition [60], sputter-deposition and pulsed laser deposition [61].

5.1. Hot isostatic pressing method

In HIP, isostatic temperature and pressure are applied simultaneously. Contrary to hot pressing, a uniform pressure is exerted in different directions (Fig. 2). HIP is used to create metals and ceramics, such as high-density ceramics and composites, components with complex shapes and it is utilized for the solid phase bonding of different or similar materials. The sample is in a gaseous medium and undergoes heat treatment accompanied by a high pressure for consolidation. One of the significant benefits of HIP is the high flexibility in specimen shape.

There are many reports concentrating on pressure sintering techniques including hot pressing (HP) and HIP to maintain the ZrO_2 and HAp phases during sintering process and decrease the sintering temperature. Moreover, pressure sintering techniques are argumentative methods with diverge conclusions and studies regarding the phase stability of the phases. Although an enhancement in reactivity are anticipated because of enhanced contact areas between diffused ZrO_2 particles and HAp matrix, there is a common agreement that the composite is significantly constant particularly after HIP. Indeed, in the composites obtained by hot pressing, a partial reaction between zirconia and HAp occurred, although, much fewer than what observed in sintering in air yet. Hence, the sintering environment can be a major factor influencing the ZrO_2 and HAp thermal stability in the composites [30]. Leong et al. [62] synthesized HAp/zirconia composites and investigated HAp decomposition for the application as dental materials. Their results indicated that HIP of HAp/ZrO_2 could greatly inhibit HAp decomposition and the highest relative density was achieved compared to other techniques.

Ergun et al. [63] prepared composites of HAp/zirconia using HIP and studied their phase stability. According to the results, phase stability of ZrO_2 and HAp in hot isostatically pressed composites was indicated. Higher ZrO_2 contents and lower sintering temperatures led to lower density in air-sintered specimens. The amount of air in the environment of sintering affects the reactivity between HAp and ZrO_2. To achieve phase stability and fully-dense HAp/ZrO_2 composites, HIP would be a suitable technique.

Lim et al. [64] studied sintering of HAp incorporated zirconia using different methods including HIP, solid-state reaction, conventional sintering and microwave sintering. They proposed that HIP revealed more satisfying results compared to other methods. Furthermore, nano structured material can be processed by alternative techniques and show better results.

5.2. Pulsed laser deposition coating technique

Laser texturing methods has been widely investigated to modify materials surface for various applications. This method is a hopeful method to progress the direct sintering of HAp on ZrO_2 substrates in order to produce appropriate coatings. It is known that mechanical interlocking produced through laser texturing is able to enhance the stability of the coating interfaces, therefore preventing delamination of coating during the implants insertion [65].

Mesquita-Guimarães et al. [65] sintered HAp coatings and 45S5 bioactive glass on micro-textured ZrO_2 via laser and evaluated osteoblasts-like cell adhesion. In vitro test indicated that, compared to flat surfaces, the squared textured pattern possessed bioactive coating and 100 µm width grooves provided an increase of 90% of cell viability after incubation for 48 hours. Hence, they showed that laser sintering is an attractive and fast method for HAp coatings.

Carmen Trincă et al. [66] studied the electrochemical properties of a novel biodegradable FeMnSi alloy coated by HAp-zirconia through pulsed laser deposition (PLD) method. Their results showed that the corrosion resistance enhanced significantly for alloys coated with HAp-ZrO_2 in comparison with uncoated sample.

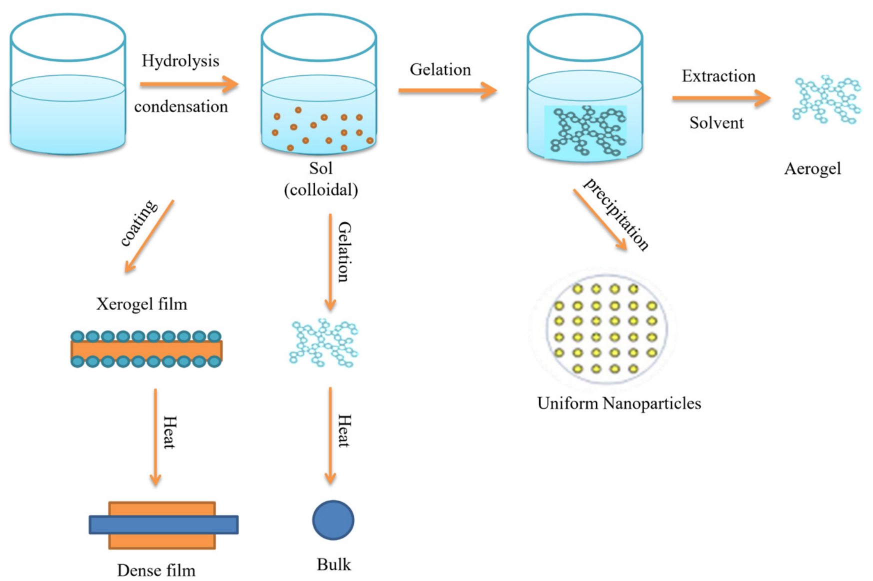

Fig. 3. Schematic illustration of sol-gel technique.

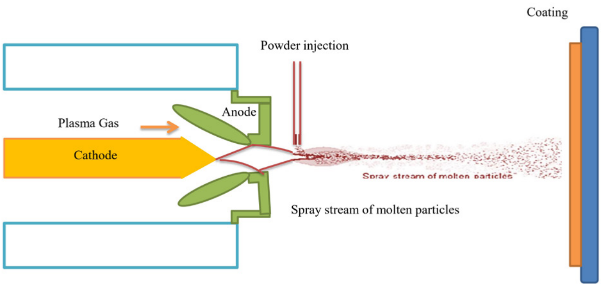

Fig. 4. Plasma spraying technique schematic illustration.

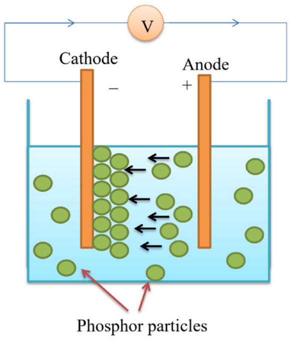

Fig. 5. Electrophoretic deposition process schematic.

Hybrid laser method was employed by Carvalho et al. [50] to functionalize zirconia surfaces by HAp for dental applications. The textures that were generated by Nd:YAG laser were produced to promote the mechanical interlocking of HAp particles, hence reinforcing its incorporation to surface of ZrO_2. For optimization of the textured pattern of ZrO_2 surface, various laser parameters were tested. Hybrid laser process was proposed to have the potential for modification and functionalization of zirconia surfaces.

5.3. Sol-gel technique

The sol–gel procedure is a wet chemical technique in which high temperatures or pH values are not required [55, 67-70] (Fig. 3). Significant reactivity owing to the large surface area of dried gels leads to a low procedure temperature [71, 72]. In addition, this technique can promote chemical homogeneity by providing a molecular mixing precursor solution. Due to its intrinsic benefits over other processes, nowadays, the sol–gel process has been highly utilized for fabricating of ceramics. The process permits the provision of a homogeneous combination of YSZ and HAp nanoparticles.

Vasconcelos et al. [73] studied the microstructure of HAp-ZrO_2 nanocrystalline composites prepared by sol–gel method. Their results showed that optimizing processing parameters could produce HAp-ZrO_2 nano-crystalline composites. The modified sol–gel process could produce a water vapor atmosphere during sintering which could control the HAp thermal stability and provide a high intergranular dispersion of ZrO_2 phase in the HAp matrix [73].

Salehi, et al. [74] studied Properties and fabrication of sol–gel isolated HAp/ ZrO_2 composites nanopowders by different yttria contents. Homogeneous composites of HAp/yttria-stabilized zirconia (HAp–YSZ) nanopowders were produced by the sol–gel technique. Due to ion exchange of zirconium and calcium between zirconia and HAp, the HAp unit cell volume enhanced in the composites. The existence of ZrO_2 nanoparticles between the HAp particles inhibited the HAp grain growth and also the inhibition of the ZrO_2 grain growth was resulted from yttrium ions segregation at the grain boundaries.

In Bollino et al. [75] research, biphasic composition of HAp and the surface modification with a tricalcium phosphate (TCP) was carried out on a zirconia substrate by utilizing a sol–gel technique. The microstructure of the conclusive HAp/TCP coatings was found to be related on the sort of zirconia substrate. The heat treatment temperatures of coating on dense and porous zirconia substrates were 750 °C and 1350 °C, respectively. In the case of dense substrate, a thick layer of nano HAp was formed, but cracking and agglomeration were observed.

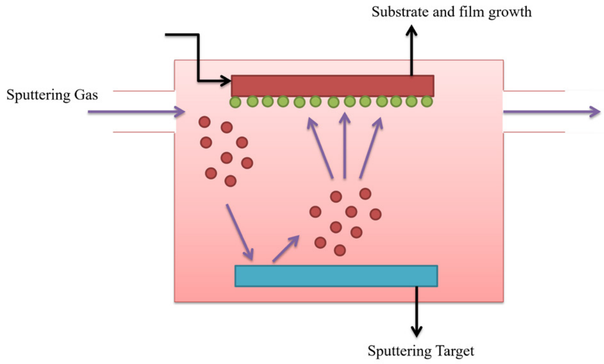

Fig. 6. Schematic of sputter coating method.

Catauro et al. [76] studied thermal and morphological characterization of the composites of HAp incorporated zirconia for biomedical applications, obtained through sol-gel method. According to the obtained results, the crystallization of Zr in the tetragonal phase occurred due to existence of HAp in the composite. Moreover, by increasing the Zr content in the composites the degree of amorphization increased.

Jin et al. [77] applied biocompatible and bioactive calcium phosphate layer on zirconia surface. HAp/ZrO_2 composites were prepared by the sol-gel technique and heat-treated at various temperatures in order to modify their chemical structure. They indicated that all materials are bioactive, consequently they can generate a HAp layer on their surfaces. Furthermore, biocompatibility enhanced with heating temperature, while the amount of HAp did not affect it significantly. On the other hand, bioactivity improved with both heat-treatment temperature and the HAp content.

Buciumeanu et al. [35] coated zirconia by zirconia/HAp composite and studied its tribological properties. Their results showed that press and sinter technique on YSZ substrates could significantly influence the performance of composite layer of bioactive zirconia. According to the results, by adding bioactive materials, the tribological characteristics and the friction coefficient were not influenced. The focus of this novel procedure on zirconia substrate was on the application of bioactive zirconia composite layer. Since there is a gradual change between the substrate and composite layer, it seems to be a suitable replacement for coatings due to reduction in interfacial residual stresses and hence it is less prone to failure.

5.4. Plasma spraying technique

One of the promising techniques of preparing coatings with special microstructural characteristics is solution precursor plasma spraying (SPPS) method (Fig. 4). Various studies have reported about SPPS method that promotes the HAp coatings. It is possible to achieve higher contents of HAp in coating with changing spraying parameters e.g. spraying distance [78, 79]. Different substrates including mild steel has been coated by HAp using air plasma spray technique [80, 81].

Hasan et al. [82] studied the mechanical properties of HAp coatings on Zr using plasma spray technique. ZrO_2/HAp composite coating on Zr by plasma spraying illustrated that compared to pure zirconia, the incorporation of HAp in ZrO_2 enhanced biological properties, whereas its biocompatibility is preserved. On the other hand, plasma sprayed

Table 1.

Various techniques used for coating HAp on ZrO_2 substrates.

Method	Coating thickness	Advantages	Disadvantages
Electrophoretic deposition	0.1–2 mm	Control of coating thickness/ morphology, low cost, rapid deposition, simple setup, uniform coating thickness, suitable for complex shaped substrate	Decomposition of HAp during sintering stages, appearance of crack in coating, high sintering temperature requirement
Sputter	0.5–3 μm	High adhesion, dense and uniform coating on flat surface	Produces amorphous coating, low deposition rate, line of sight technique, costly, time-consuming
plasma spraying	<20 μm	Quick bone healing, less possibility of coating degradation, high deposition rate, low cost	Unable to form complete crystalline coating, relatively weak adhesion, non-uniformity in coating density, phase change and grain growth of the material because of high temperature, change of HAp structure during coating
Sol-gel	50–400 nm	Very thin and high purity coatings, low processing temperature, high corrosion resistance, suitable for complex shaped substrate, uniformity in coating	Expensive raw materials, high permeability, difficult to control porosity, requirement of posttreatment (curing), Appearance of edge cracking
Pulsed laser deposition coating	0.05–5 μm	Control of deposition factors, amorphous and crystalline coatings, suitable for porous, dense coating	Line of sight technique, requirement of pretreatment of surface, lack of uniformity, expensive, low deposition rate
HIP	0.2–2.0 mm	Good temperature controlling, dimensional limitation, dense coating, no shape	Reaction of encapsulation material with HAp coating, incompatibility of thermal expansion coefficient, costly, requirement of high temperature, unable to coat complex shaped substrate

coatings suffer from residual stress and lack of uniformity in coatings on complex-shaped Zr implants.

5.5. Electrophoretic deposition

Electrophoretic deposition is a coating method, in which through the influence of an external electric field colloidal particulates migrate and are deposited on an electrode (Fig. 5). Ceramic coatings are able to be produced by this technique and the method has the capability to be used for complex objects coating due to being cost-effective and flexible. This approach allows controlling of the microstructure, thickness and composition of coatings hence electrophoretic deposition is a useful method especially in the HAp deposition [30].

Sandhyarani et al. [83] fabricated nanostructured ZrO_2/HAp coating on zirconium and studied in-vitro performance of manufactured composites. HAp particles were dragged into the evacuation channels, during the film growth step, then by electrophoretic deposition process entrapped into the oxide film. Due to residing of Ca (generating from HAp melting) in Zr sites, zirconia is stabilized. After immersing in SBF for 8 days, apatite layer similar to bone was formed on all surfaces of ZrO_2/HAp films showing their considerably increased in-vitro bioactivity. The cell adhesion test results indicated that the human osteosarcoma cells on the surface of ZrO_2/HAp film could propagate, append and adhere very well [84].

Sakthiabirami et al. [85] coated a composite of glass/zinc-HAp on glass-infiltrated zirconia to tailor interfacial interaction. The surface stabilization of HAp (Ca^{+2} cations) was done by chemical adsorption of non-dissociated 2-propanol and monochloroacetic acid (MCAA) molecules through Cl^- followed by protons dissociation, leading to negatively charged HAp particles.

Drdlik et al. [86] used electrophoretic deposition to prepare HAp/ZrO_2 microfiber with controlled fracture and microporosity properties. Vickers hardness and elastic modulus of composites enhanced with dispersions milling time prior to electrophoretic deposition and were reduced with the ZrO_2 microfibers amount in the coatings, which is related to the density of composites. As a result of tougher β-TCP phase, finer microstructure, and the existence of orientated microfibers of zirconia, fracture toughness of the composites increased significantly compared to pure HAp.

Farnoush et al. [87] prepared HA/YSZ nanocomposite coatings on Ti–6Al–4 V substrate using electrophoretic deposition and studied the stability of suspension and its effect on bonding electrochemical behavior and bonding strength. According to the obtained results, incorporation of 20 wt. % YSZ resulted in the reduction of corrosion rate of coated specimens, whereas linear polarization resistance and corrosion potential increased.

5.6. Sputter coating method

Sputter coating technique is a kind of vapor deposition technique, in which high energy particles are ejected from a target and bombard a substance and is appropriate for thin coatings. For elimination of the substance from the target with negative charge, a gas plasma including xenon, krypton, neon and, argon is used and then the particles are deposited on the substrate (Fig. 6) [30].

Kong et al. [88] used magnetron sputtering for the preparation of HAp-zirconia coatings on Ti6Al4V. They proposed that the porous surface of the deposited coating is suitable for conduction of bone tissue growth. The bonding strength decreased by increasing HAp content and the residual stress reduced by appropriate increasing of HAp contents.

Ozeki et al. [89] fabricated thin films of HAp on zirconia using a sputtering technique. During hydrothermal treatment, the recrystallization of coated films occurred to decrease dissolution. After the films recrystallized under the hydrothermal treatment, bone formation area on the coating for both the Ti and ZrO_2 substrates increased. This value was reported to be higher for the ZrO_2 substrate. Table 1 summarizes the applied methods to prepare HAp-coated ZrO_2 for potential dental implant.

6. Conclusions and future insights

Although hydroxyapatite (HAp) is highly biocompatible, it has low mechanical properties. Instead, zirconia exhibits bioactivity, biocompatibility, and good mechanical and aesthetic properties enhancing the quality of the dental implants. Thus, HAp incorporated in zirconia provide high stability and protection in long time promoting integration of the dental implants. These composites are promising novel bone restorative materials having properties similar to human bone. Furthermore, the surface modification of zirconia composites can be obtained by different types of HAp coatings. Therefore, these materials can be considered as alternatives to conventional counterparts in dentistry such as titanium and its alloys due to their advantages in dental implant applications.

Acknowledgments

The authors received no financial support for the research, authorship and/or publication of this article.

Conflict of Interest

All authors declare no conflicts of interest in this paper.

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