

# Current Status of Ceramic Coatings for Dental Implants

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The continuing efforts to improve ceramic coatings for metallic dental implants have resulted in higher quality plasma-sprayed hydroxylapatite (HA) coatings and have led to the development of a number of other coating materials and coating techniques that can be used in cases where ceramic coatings with special properties are desired. The primary emphasis of companies that produce coated implants has been on optimization of the plasma spray process, and today's commercially available HA coatings exhibit higher bond strength and greater crystallinity than coatings of 5 and 10 years ago. However, the limitations of the plasma spray process are widely recognized, such as when coating porous substrates and in those situations where a higher bond strength is desirable. Following is a description of the current state of the art of plasma-sprayed HA coatings and a discussion of the various alternative coating materials and available techniques (or in the process of being developed). A projection is also put forth as to future expectations, especially as to the suitability of the various ceramic coatings for use with bone inductive agents.

## TYPES OF CERAMIC COATINGS

The types of ceramic coatings available include both the bioactive type, such as the calcium phosphates, and the inert ceramics such as alumi-

*There are various ceramic coatings available for dental implants. From a commercial standpoint, plasma-sprayed hydroxylapatite (HA) is the most popular.*

*These coatings are typically partially amorphous after processing and contain crystalline phases other than HA. Plasma-sprayed HA and the other bioactive ceramic coating materials have been shown to enhance bone apposition as compared with uncoated metal implants. Some of the other available materials include the bioglasses, other calcium phosphates such as fluorapatite and tricalcium phosphate, and the inert ceramics such as alumina. The plasma-spray process is not optimum for all types of ceramic coatings, because it is not suitable for coating porous surfaces; the exact control of structure and chemistry is difficult with this process, and bond strength is not as high as is desired for some applications. Alternative methods for coating include sol-gel processing, ion beam and radio frequency (RF)*

*sputtering, pulsed laser deposition, hot isostatic pressing, and electrophoretic deposition. The use of osteoinductive agents in conjunction with ceramic-coated implants is of current interest, and the degree and type of bonding of these agents appear to vary with the composition of the ceramic coating. Because there seems to be no satisfactory means of incorporating osteoinductive agents into ceramic coatings during any of the conventional coating procedures, the best approach seems to be to diffuse the agents into the coating after processing. Other possibilities include the tethering of the agents to the surface of the ceramic by suitable organic molecules or the placing of the agent in some carrier material such as a cement, which is placed around the implants. (Implant Dent 1998;7:315-322)*

**Key Words:** dental implants; hydroxylapatite; ceramic coatings; coating techniques; calcium phosphate

num oxide and zirconium oxide. Some of the ceramic coating materials and their compositions are listed in Table 1. All of the bioactive ceramics, including the bioglasses, have been documented to produce a calcium phosphate layer on the unmodified surface when used in vivo or in a simulated physiological solution. Calcium phosphate materials can vary somewhat in composition (as shown in Table 1), but of primary importance, as far as tissue

response is concerned, appears to be the amount of calcium and phosphate ions released per given time. The presence of Ca and P ions in the area around the implant often results in enhanced bone apposition as compared with the more inert ceramic and metallic surfaces.<sup>1</sup> This occurrence is perhaps because the ions released from the implant surface signal the body to initiate cell differentiation, thus leading to bone formation at an earlier time.

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**Table 1.** Ceramic materials present in some dental implant coatings

Hydroxyapatite (HA)	$\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$
Tricalcium phosphate (TCP)	$\text{Ca}_3(\text{PO}_4)_2$ , $\alpha$ , $\beta$ , some with MgO
Fluorapatite (FA)	$\text{Ca}_{10}(\text{PO}_4)_6\text{F}_2$
Tetracalcium phosphate (TTCP)	$\text{Ca}_4\text{P}_2\text{O}_9$
Calcium pyrophosphate	$\text{Ca}_2\text{P}_2\text{O}_7$
Brushite	$\text{CaHPO}_4$ , $\text{CaHPO}_4 \bullet 2\text{H}_2\text{O}$
Bioglasses (Bioglass™, AW Glass Ceramic™)	$\text{SiO}_2$ -CaO-Na <sub>2</sub> O-P <sub>2</sub> O <sub>5</sub> -MgO, etc.
Aluminum oxide	$\text{Al}_2\text{O}_3$
Zirconium oxide	$\text{ZrO}_2$

The least dissolvable of the calcium phosphate coatings is dense, sintered HA. It is possible to form and sinter cylindrical sleeves of HA and then slide them over Ti implant cores, but these do not appear to be available as commercial products. The sintering of the ceramic in a separate procedure (not on the metallic implant) allows the formation of a structure with much higher density and crystallinity than can be accomplished by conventional coating processes; thereby resulting in a more stable coating, but one that exhibits less ion release. Perhaps the coating technique that comes closest to producing dense, 100% crystalline HA coatings without additional heat treatment is hot isostatic pressing, but most other coating techniques cause significant alteration of the starting material.

The most stable of the plasma-sprayed calcium phosphate coatings is fluorapatite (FA), which is capable of retaining in large part both its fluorine constituent and high crystallinity during the high temperature plasma spray process.<sup>2</sup> Fluorapatite is not available on commercial products in the United States but has been tested rather extensively in Europe. This material has been shown to have *in vivo* response similar to

plasma-sprayed HA. In one study, Overgaard et al<sup>3</sup> found no difference in push-out strength or amount of bone for FA and HA in a loaded canine model; while in an unloaded model, FA encouraged significantly more bone ingrowth. Other relevant findings from that study were that all coatings remained on the implants during the push-out test (indicating good bond strength with titanium), and no evidence of fluorine was found in the tissue around the implants.

Plasma-sprayed HA typically has a crystallinity of around 60% to 70%, but higher crystallinity numbers can be obtained if the coated implant is heat treated at a suitable temperature after the deposition process. One study showed that a low crystallinity (46% HA) plasma-sprayed implant exhibited about three times the dissolution of Ca ions as a higher crystallinity (75% HA) material.<sup>4</sup> All of the other calcium phosphate materials such as brushite, TCP, etc., are more dissolvable than FA or HA in a pH range of from 4 to 8, (assuming materials of the same density are being compared). The other type of bioactive ceramics, the bioglasses, are typically surface reactive materials, as a reaction layer of 150  $\mu\text{m}$  or so forms rather quickly

on exposure to solution. However, these materials remain long-term in the body, as dissolution of the remainder (bulk) of the implant slows to a very low rate after the initial surface reaction occurs and a carbonated hydroxylapatite layer forms *in vivo* or *in vitro*.<sup>5</sup>

The inert ceramic implant materials, such as aluminum oxide, are rarely used as coatings because they do not appear to be as osteoconductive as the more bioactive calcium phosphate materials. Inert ceramics do not typically exhibit any hydroxide formation or change in oxide state of the surface and do not appear to encourage the formation of a calcium phosphate layer *in vivo* from ions present in the body. Also, similar to inert metals such as titanium, they have not been demonstrated to form a chemical bond with bone. There have been some attempts to coat inert ceramics with calcium phosphate to increase their bioactivity. One example is the coating of AW glass ceramic onto porous-surfaced aluminum orthopaedic implants;<sup>6</sup> but there appears to have been little interest in that approach for ceramic dental implants.

## COATING METHODS

Some of the available methods of applying ceramic materials as coatings for dental implants are listed in Table 2. It is important to realize that all coating processes are likely to alter the composition of the starting material to some degree and also have the potential for introducing impurities into the coating.

### Plasma Spraying

Plasma spraying is the most common coating method for dental implants, because almost all the commercial HA coatings are produced by this technique. This method involves the use of a carrier gas, which is ionized (thus forming a plasma) and superheated so that the particles of the starting material (generally HA) undergo partial melting as they are propelled toward the substrates to be coated. Coatings around 50  $\mu\text{m}$  typically are produced on a roughened titanium or alloy

**Table 2.** Techniques for applying ceramic coatings to dental implants and characteristics of HA coatings produced using each method

Technique*	Thickness ( $\mu\text{m}$ )†	Structure‡	Porous Sub§
Plasma spraying	40–60	No	No
Ion beam sputtering	1–2	No	No
RF sputtering	1–3	No	No
Pulsed laser deposition	1–5	Possible	No
Hot isostatic pressing	20–100	Yes	No
Electrophoretic deposition	10–30	Yes	Yes
Electrocodeposition	20–40	Yes (+metal)	Yes
Sol-gel Processing	5–20	No	Yes

\* Technique—Coating method.

† Thickness—Typical thickness range.

‡ Structure—Retention of the composition of the starting material (usually HA).

§ Porous Sub—Suitability for completely coating porous substrates.

surface for a typical HA plasma-sprayed endosseous implant. Advantages of the plasma spray process are that a) it is relatively inexpensive, and b) the mechanical properties of the metallic substrate are not compromised during the coating process. Limitations of the plasma spray technique are that it is line-of-site, and only mechanical bonding with the metallic implant surface can be expected unless further operations (such as heat treatment) are performed.<sup>7</sup> The main source of contamination appears to be copper from the nozzle of the sprayer. However, this does not seem to be a serious problem for manufacturers and can be dealt with rather easily by visual detection and removal of the contaminated implants.

The plasma spray process produces coatings that can be described as partially amorphous, partially dehydroxylated, and which contain some crystalline phases other than HA (TCP, TTCP, etc.).<sup>8</sup> They also may contain a few percent of CaO, which accounts for the rather rapid release of Ca within a short time of implantation. Certainly the presence of amorphous CaP and crystalline phases other than HA leads to a much faster ion release rate and coating degradation as compared to dense, sintered HA. There is some speculation that the dissolvable nature of the coatings is one of the primary reasons for the faster bone apposition observed around HA plasma-sprayed titanium implants as opposed to uncoated titanium implants and to amorphous calcium phosphate coatings as compared with HA coatings.<sup>9</sup>

#### **Vacuum Deposition Techniques**

There are several methods of putting thin coatings of ceramics on metals, as is done routinely in the electronics and other industries. These usually involve bombarding a "target" of the materials in a vacuum chamber with the resulting sputtered or ablated atoms or particles moving through the chamber to coat properly positioned substrates. These techniques include ion beam sputtering, RF sputtering, and pulsed laser deposition<sup>10</sup> and are all relatively expen-

sive and only capable of depositing coatings in the order of a few micrometers. These vacuum deposition techniques produce high quality coatings with good bonding to either smooth or rough titanium surfaces but usually require a heat treatment in a controlled atmosphere to attain high crystallinity. The efficacy of these very thin coatings is unknown at this time; there is some concern that the coating may resorb in the body before causing the desired effect. For example, some of our work has shown that a 1- $\mu$ m HA coating will dissolve in 9 weeks compared with 18 weeks for a 1- $\mu$ m FA coating produced using an identical procedure involving an ion beam sputtering process with a postdeposition heat treatment.<sup>11</sup> Although some initial results in Europe have indicated that sputter deposited coatings are quite biocompatible, there is as yet little evidence to demonstrate the clinical effectiveness of these very thin coatings.

#### **Sol-gel and Dip Coating Methods**

Studies on the use of sol-gel technology for coating dental implants have recently been initiated. This method has been used for depositing other types of thin coatings, such as super conducting thin films for electronic devices. In this technique, precursors of the final product are placed in solution, and the metal implant to be coated is dipped into the solution, withdrawn at the prescribed rate, then heated to create a more dense coating. Advantages of sol-gel processing include small crystallite size and high strength, and the potential for applying a uniform coating to porous substrates. Zirconium oxide coatings for implants using the sol-gel process have been developed,<sup>12</sup> and work on calcium phosphate implant coating produced by this method has been initiated.

A dip-coating method has been developed by Maruno et al,<sup>13</sup> in which HA particles are mixed with a lower melting alumina borosilicate glass and then coated on a titanium implant. The coating is fired at 800°C to 900°C to melt the carrier glass and achieve bonding to the metallic substrate. The process can be

repeated until a relatively thick coating (e.g., 100  $\mu$ m) consisting of an HA/glass mixture can be obtained.

#### **Hot Isostatic Pressing**

Hot isostatic pressing (HIP) is used to develop the highest density and strength possible in crystalline ceramic materials. In this technique, both heat and pressure are used to densify ceramic powder (such as alumina or HA) into a solid ceramic of high strength. In the case of an HA coating on a titanium implant, the HA powder is applied to the implant surface, an inert foil is placed over the powder to facilitate uniform densification, and both heat and pressure are applied.<sup>14</sup> As the coating is densified into a solid mass, it becomes bonded to the implant at the same time. The advantage of this method is that lower temperatures can be used than if pressure were not applied. This allows the mechanical properties of the titanium or other implant metal to be maintained. Disadvantages are a) the higher expense; b) the necessity of removing the inert foil or other encapsulating material; and c) the potential for contamination.

#### **Electrolytic Processes**

Electrophoresis and electrolytic codeposition are two processes that deposit HA or suitable bioceramic particles out of a bath of the proper chemistry. The advantages of these two solution deposition techniques are that porous surfaced materials can be uniformly coated, and the original composition of the ceramic (e.g., HA) can be maintained in most cases. The principle behind the electrophoretic deposition of HA is that the weak charge (negative) present on an HA particle can be used to cause the particle to move to a charged electrode (positive). The weakly bound particles are then sintered onto the metal implant to gain density and bond strength.<sup>15</sup> This method typically produces minimally bound coatings (even after sintering) and appears to be best used for porous implant surfaces. The electrocodeposition process is somewhat different in that both metal and HA are deposited simultaneously out of

an acid solution containing salts of the metals to be deposited.<sup>16</sup> In this case, a layer of metal (usually about 20  $\mu\text{m}$  thick) pins the ceramic particles to the implant surface. Higher bond strengths are common with this process with no need to sinter the coating. One disadvantage of the electro-codeposition process is the lack of 100% bioactive material on the surface (i.e., some metal is present), unless a layer of pure HA, brushite, or other ceramic is deposited in a separate operation. Another potential problem is that galvanic corrosion may occur due to the difference in composition between the metallic portion of the coating and the implant core.

In summary, none of the coating techniques discussed produce HA coatings with both high crystallinity and high bond strength in their present state of development. Heat treatments may be used to increase crystallinity, however, they are not widely used because of the added expense and increased possibility of contamination of the coatings. Manufacturers can often obtain the desired crystallinity (e.g., higher than 80% in some cases) during the plasma spray coating operation itself without the need for additional heat treatment.

## COATINGS AND BONE INDUCTIVE AGENTS

A number of the coating methods that have been addressed show some promise as alternatives to the plasma spray process; especially for coating porous surfaced implants or possess the ability to control the coating chemistry and structure to a greater extent than plasma spraying. Another factor for consideration is what is the most appropriate coating material and/or coating method if osteoinductive agents such as growth factors (e.g., TGF- $\beta$ ) or bone morphogenic proteins (e.g., BMP-2) are to be used in conjunction with a ceramic-coated implant. In other words, the question then becomes which type of calcium phosphate coating (and coating method) creates an implant surface that either releases bone growth factors to the surrounding tissues or provides the

proper environment for these osteoinductive agents to function properly.

It is important to first consider the nature of the bone inductive agents to ascertain whether one or more should be used in conjunction with a ceramic-coated implant device. A typical bone morphogenic protein such as BMP-2 induces stem cell differentiation into osteoblasts capable of producing bone. However, early work has shown that it is not likely that BMPs can be deposited in a concentrated amount around an implant, such as by injection, after the implant is in place. A suitable carrier, or some other means of moderating the release rate is important. One group found that when the BMP-2 was combined with human fibrin the result was a more level release of the osteoinductive agent with time and a more successful result.<sup>17</sup> Therefore, it appears that bone growth factors must be released by the implant or other carrier in a well-controlled manner over the proper time period following implantation.

Studies have shown that the use of bone growth factors may enhance bone formation around implants, although in some cases results are not overly favorable to the use of such factors. For example, Lind et al<sup>18</sup> used .3  $\mu\text{g}$  and 3  $\mu\text{g}$  amounts of TGF- $\beta$  adsorbed onto HA-coated implants in a canine study and found that bone ongrowth increased by 1/3 using the .3  $\mu\text{g}$  quantity only, but bone volume and mechanical push-out strength were not significantly increased. Bone growth factors adsorbed on TCP-coated implants have been used in a weight-loaded animal model (dogs). Bone ongrowth on the TCP with adsorbed growth factors was higher by 59%, but the volume of bone in the gap and the push-out strength was not significant from the control with contained no TGF- $\beta$ .<sup>19</sup>

Several questions arise when considering the use of a bone growth factor with a ceramic-coated dental implant:

- What type of surface is optimum for binding and releasing osteoinductive agents?
- Does the implant surface need to

be porous to contain a sufficient quantity of the agent?

- Does the coating containing the agent need to be resorbable to provide sustained release?
- Does the osteoinductive material need to be bound by the implant or can it just be incorporated into a cement placed around the implant during the surgical procedure?

As the efficacy of bone inductive agents is still being assessed in ongoing *in vivo* studies, questions remain about the role of the ceramic implant surface in controlling the release rate. It appears certain that any bone growth factors could not be mixed into the powder before plasma spraying or experience any high temperatures during processing of the coating by any means. Even low temperature coating processes such as ion beam deposition may experience temperatures of up to 150°C, in addition to the requirement of processing in a high vacuum that also may cause denaturation of some organic agents. The electrophoretic codeposition typically operates at room temperature, but the high acidity of the bath would probably cause denaturation of organic compounds. Electrophoretic deposition does not result in coatings with sufficient bond strength unless a subsequent heat treatment of at least 600°C is performed after the coating operation. This would not be suitable for incorporation of organic compounds if this procedure was followed. In summary, if bone inductive agents are to be incorporated into a coating produced using any of the techniques discussed above, it appears that the processing of the coating, including densification and bonding to the metal substrate, must occur before incorporation of the organic agent.

One possible means to produce ceramic surfaces which release inductive agents is to create a layered coating in which the initial layer can be deposited on metal, densified and bonded, and then a more porous layer placed that exhibits higher resorbability and a higher internal surface area, which is more suitable for incorporation of growth factors.

Some means of diffusing those agents into the coating (such as by placing the porous-coated implant under vacuum) and binding them in place to allow a slow release (with time) to the surrounding tissue would have to be developed.

It appears that these osteoinductive materials could best be placed within a ceramic coating after the processing is completed, such as by diffusion of the agents into a porous structure. Calcium phosphate surfaces appear to have varying abilities to bind growth factors based on their composition. For example, Downes et al<sup>20</sup> found that growth factors adhered to plasma-sprayed HA more firmly than to heat treated HA; and bonding appeared to be ionic in the former as opposed to covalent for the latter. Another approach is to tether the biomolecules to the ceramic surface by an appropriate polymeric material, such as a protein chain with specific binding sites. To regulate the release rate of the BMP or other osteoinductive agent, it may be necessary to have different binding molecules with a range of release rates to promote the proper response. Perhaps further research will show that the bone growth factors do not need to be placed on implants but may be incorporated in either a calcium phosphate or a polymeric cement or similar material. This material would be placed around the implant and resorb at a predictable rate, releasing bone growth factors and being replaced by bone within the desired time period.

Because it appears that incorporating or binding growth factors to a ceramic coating may be expensive and quite difficult because of the necessity of densifying and bonding the coating to the underlying metal, it is important to consider whether these agents are actually necessary with a typical calcium phosphate coating such as plasma-sprayed HA. The calcium phosphate materials are classified as osteoconductive, and Ca ion has been found to stimulate healing activity in the bone around a coated implant. Under certain conditions a ceramic coating of the proper composition may adsorb the bioactive factors which initiate bone for-

mation directly on the ceramic surface. In these and other specific cases, ceramic coatings appear to exhibit osteoinductive behavior. For example, one porous structure derived from coral with a surface converted to HA has been demonstrated to cause bone growth in soft tissue in an animal study.<sup>21</sup> A possible explanation is that bone growth factors may become concentrated on the surface of the ceramic and cause differentiation of stem cells into osteoblasts. It has been speculated that some nonceramic materials such as polypeptides may also be able to bind and/or concentrate osteoinductive factors leading to enhanced bone growth, even though they are not themselves osteoinductive. Although there is no conclusive evidence this phenomenon occurs in humans, the possibility remains that ceramic coatings (and certain other materials) of the proper surface chemistry may cause rapid bone apposition without the need for externally applied bone growth factors or other osteoinductive agents.

## CONCLUSION

A large number of ceramic coatings can be placed on dental implants using a variety of techniques. The final properties of a ceramic coating are influenced by the method of processing. Certainly, numerous factors will influence the *in vivo* behavior of these coatings, and there is disagreement as to what constitutes the ideal coating material. By far the most popular ceramic coating from a commercial standpoint is plasma-sprayed HA; but coatings called "HA" can behave quite differently from each other *in vivo* because of differences in composition, structure, and porosity. Most of the calcium phosphate and bioglass coatings are called "osteoconductive" as opposed to "inert" classification given to other ceramics, carbon, titanium, and cobalt alloys. It does appear that release of calcium and phosphate ions from biodegradable coatings may somehow signal the body in a manner favorable to earlier bone formation, and a more dissolvable coating such as plasma-sprayed HA may in

fact be superior to a fully crystalline, less dissolvable HA or inert ceramic coatings as far as stimulating bone growth. There are, however, some concerns about the stability of degradable coatings on a long-term basis.

Bioactive ceramic coatings are considered to be osteoconductive, but in specific cases involving certain porous calcium phosphate coatings, there may be a degree of osteoinduction possible (although this has not been demonstrated conclusively at this time). The early work on incorporation of bone growth factors have shown that ceramic, and some polymeric, surfaces are more suitable than metals for inclusion or binding of some osteoinductive agents, but in some cases at least there appears to be little enhanced effect with the use of growth factors. It remains to be seen whether one or more of the ceramic materials of appropriate porosity and composition when applied to a metal implant using a suitable technique will prove to be ideal for incorporating and releasing osteoinductive agents.

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## Abstract Translations [German, Spanish, Portuguese, Japanese]

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**ABSTRACT:** Von den verschiedenen für Zahnimplantate erhältlichen keramischen Beschichtungen ist nach dem Plasmaspritzverfahren aufgetragenes Hydroxylapatit unter wirtschaftlichen Gesichtspunkten das beliebteste. Diese Beschichtungen sind nach der Verarbeitung normalerweise amorph und enthalten außer HA noch weitere kristalline Phasen. Plasmagespritztes HA und die anderen bioaktiven keramischen Beschichtungsmaterialien haben sich im Vergleich zu unbeschichteten Metallimplantaten als vorteilhaft bezüglich der Knochenanlagerung erwiesen. Zu den sonst erhältlichen Materialien gehören Bioglas, weitere Kalziumphosphate wie Fluorapatit und Trikalziumphosphat sowie die inerten Keramiken wie zum Beispiel Aluminium. Das Plasmaspritzverfahren ist nicht für alle Arten keramischer Beschichtungen optimal geeignet, da es für die Beschichtung poröser Oberflächen untauglich ist, die genaue Kontrolle der Struktur und Chemie bei diesem Verfahren schwierig ist und die Bindekraft nicht so stark ist wie das bei einigen Anwendungen wünschenswert wäre. Zu den alternativen Beschichtungsmethoden gehören die Solgelverarbeitung, Ionenstrahl- und HF-Zerstäubung, Impulslaserbeschichtung, isostatisches Heißpressen und elektrophoretische Lackierung. Der Einsatz zur Knochenbildung anregender Substanzen in Verbindung mit keramisch beschichteten Implantaten ist von aktuellem Interesse, wobei Bindungsgrad und -beschaffenheit dieser Substanzen in direktem Zusammenhang mit der jeweiligen Zusammensetzung der keramischen Beschichtung zu stehen scheinen. Da kein zufriedenstellendes Mittel bekannt ist, mit dessen Hilfe die knochenbildenden Substanzen bei den herkömmlichen Beschichtungsverfahren in die keramischen Beschichtungen eingebunden werden können, scheint es das beste zu sein, diese Substanzen einfach nach der Bearbeitung in die Beschichtung eindiffundieren zu lassen. Weitere erfolgversprechende Ansätze könnten in der Anbindung dieser Substanzen an die keramische Oberfläche mit Hilfe von geeigneten organischen Molekülen oder der Vermischung der Substanz mit einem Trägermaterial wie zum Beispiel Zement bestehen, das dann um die Implantate herum aufgetragen wird.

**SCHLÜSSELWORTE:** Zahnimplantate, Hydroxyapatit, keramische Beschichtungen, Beschichtungstechniken, Kalziumphosphat

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**ABSTRACTO:** De los distintos recubrimientos cerámicos disponibles para uso en implantes dentales, la hidroxiapatita rociada con plasma es la más popular desde el punto de vista comercial. Estos recubrimientos son típicamente parcialmente amorfos después del procesamiento y contienen fases cristalinas distintas que HA. La HA rociada con plasma y los otros materiales para recubrimientos cerámicos bioactivos han demostrado mejorar la yuxtaposición del hueso comparados con los implantes de metales sin recubrimiento. Algunos de los otros materiales disponibles incluyen los biovidrios, otros fosfatos de calcio tales como fluapatita y fosfato tricálcico, y las cerámicas inertes tales como alumina. El proceso de rociado con plasma no es óptimo para todos los tipos de recubrimientos cerámicos, ya que no es óptimo para el recubrimiento de superficies porosas, control exacto de la estructura y la química es difícil con este proceso, y la resistencia del pegado no es tan alta como se desea en algunas aplicaciones. Métodos alternativos de recubrimiento incluyen procesamiento sol-gel, rayo iónico y pulverización RF, deposición de láser con pulsos, presión isostática caliente, y deposición electroforética. El uso de agentes osteoinductivos junto con implantes recubiertos en cerámica es de interés actual, y el grado y tipo de pegado de estos agentes parece variar con la composición del recubrimiento cerámico. Mientras que parece no existir medios satisfactorios de incorporar agentes osteoinductivos en los recubrimientos cerámicos durante ninguno de los procedimientos de recubrimiento convencionales, el mejor método parece ser propagar los agentes en el recubrimiento después del procesamiento. Otras posibilidades que podrían usarse incluyen la atadura de los agentes a la superficie de la cerámica por moléculas orgánicas apropiadas, o al colocar al agente en algún material de transporte tal como el cemento que se coloca alrededor del implante.

**PALABRAS CLAVES:** implantes dentales, hidroxiapatita, recubrimientos cerámicos, técnicas de recubrimiento, fosfato de calcio

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**SINOPSE:** Dos vários revestimentos de cerâmica disponíveis para implantes dentários, a hidroxiapatita borrifada com plasma é a mais popular do ponto de vista comercial. Estes revestimentos são parcialmente amorfos após processamento e contêm outras fases cristalinas além da HA. A HA borrifada com plasma e outros materiais de revestimento de cerâmica bioativas também demonstraram aprimorar a aposição do osso em comparação a implantes metálicos não revestidos. Alguns dos outros materiais disponíveis incluem biovidrios, outros fosfatos de cálcio tais como fluorapatita e fosfato de tricálcio e cerâmicas inertes como alumina. O processo de borrifado de plasma não é o ideal para todos os tipos de revestimento de cerâmica, do mesmo modo que não é ideal para superfícies de revestimento porosas, visto que o controle preciso da estrutura e da química é difícil com este processo. A força de aglutinação não é tão alta quanto a desejada para algumas aplicações. Métodos alternativos para revestimento inclui o processamento sol-gel, feixe de íon e crepitação de radiofrequência, deposição de laser pulsado, pressão iostática quente e deposição eletroforética. O uso de agentes osseoindutivos em conjunto com implantes recobertos de cerâmica é do interesse atual, e o grau e o tipo de aglutinação que desses agentes parece variar com a composição do revestimento de cerâmica. Parece não haver uma maneira satisfatória de incorporar agentes osseocondutivos em revestimentos de cerâmica durante os procedimentos de revestimentos convencionais, o melhor método seria o de difundir os agentes no revestimento após o processamento. Outras possibilidades poderiam ser a inclusão de fixação de agentes a superfície da cerâmica por moléculas orgânicas ideais ou a colocação do agente em algum material transportador como o cimento que é aplicado ao redor dos implantes.

**PALAVRAS-CHAVES:** implantes dentários, hidroxiapatita, revestimento de cerâmica, técnicas de revestimento, fosfato de cálcio

## デンタルインプラントにおけるセラミックコーティングの現状

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### 概要：

デンタルインプラントに使用可能な各種のセラミックコーティングの中でも、血漿スプレーされたヒドロキシルアパタイトは商業的に人気が一番高い。これらのコーティングは普通、処置後も部分的に無定型で、ヒドロキシルアパタイト以外の結晶性フェーズも内在している。血漿スプレーされたヒドロキシルアパタイトやその他の生体活性セラミックコーティング材料は、コーティングのない金属製インプラントにくらべ骨接合をより促進することが知られている。他に使用される材料には、バイオガラス、フルオールアパタイトや磷酸トリカルシウムなど他の磷酸カルシウム類、アルミナなどの不活性セラミックなどがある。血漿スプレーの過程はすべてのタイプのセラミックコーティングに向いているとは言えない。多孔性表面のコーティングは構造的・化学的コントロールが困難であり、ある種の場合は接合強度も不足する。これに代わる方法に、ゾルゲル処理、イオンビームとRFスパッタリング、パルスレーザー・デポジション、ホットアイソスタティック・プレスリング、エレクトロフォレティック・デポジションなどがある。また、骨誘導性物質をセラミックコートされたインプラントに併用する方法が、現在注目されており、これらの材料の接合能力と接合タイプは、セラミックコーティングの素材により大きく左右されるようである。従来のコーティング法の過程では、骨誘導性物質をセラミックコーティングに導入する有効な方法が見つかっていないため、処置後にこのような物質をコーティングに拡散させるのが、現在最良の方法である。その他の方法としては、適切な生体材料によりセラミック表面に骨誘導物質を繋ぎとめる方法や、それをセメントなどの搬送材料にのせインプラントの周辺に置く方法の可能性として考えられる。

### キーワード：

デンタルインプラント、ヒドロキシルアパタイト、セラミックコーティング、コーティング技術、磷酸カルシウム

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