# Systematic Review of Current Dental Implant Coating Materials and Novel Coating Techniques

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***Purpose:*** Titanium dental implants have a high success rate; however, there are instances when a modified surface may be desirable. The aim of this article was to systematically review the different types of implant coatings that have been studied clinically, in vivo and in vitro, and the coating techniques being implemented. ***Materials and Methods:*** The literature was searched electronically and manually through The Cochrane Library, Medline, and PubMed databases to identify articles studying dental implant surfaces and coating techniques. The database search strategy revealed 320 articles, of which 52 articles were considered eligible—40 in relation to implant coatings and 12 to the coating technique. An additional 30 articles were retrieved by hand search. ***Results:*** Several materials were identified as possible candidates for dental implant coatings; these include carbon, bisphosphonates, bone stimulating factors, bioactive glass and bioactive ceramics, fluoride, hydroxyapatite (HA) and calcium phosphate, and titanium/titanium nitride. HA coatings still remain the most biocompatible coatings even though the more innovative bioglass suggests promising results. The most common coating techniques are plasma spraying and hydrocoating. More recent techniques such as the nanoscale technology are also discussed. ***Conclusions:*** Several implant coatings have been proposed, and some appear to give better clinical results and improved properties than others. Clinical trials are still required to provide compelling evidence-based results for their long-term successful outcomes. *Int J Prosthodont 2015;28:51–59. doi: 10.11607/ijp.4124*

Osseointegration consists of a series of bone modeling and remodeling processes. It has actually been defined as the direct structural and functional connection between living bone and the surface of a load-bearing artificial implant.[1] The success of osseointegration depends on the quality, distribution, and amount of bone present at the site of the dental implant. Two theories regarding osseointegration have been proposed by Brånemark and Weiss.[2,3] The difference between the proposed systems is the presence of a layer of connective tissue or fibro-osseous ligament between the implant surface and the adjacent bone. The presence of bone adjacent to the implant surface is determined by the surgical technique and also by the implant material, design, and surface texture. One can link the osseous stability of the implant to its surface texture and characteristics. Optimal osseointegration depends on the implant material characteristics, implant loading, the surgical technique used, and the type of bone at the implant insertion site.[4,5] On a long-term basis, this also depends on the prosthetic design and occlusal loading.[5]

Titanium (Ti) is the most widely used material for dental implants due to its minimal toxicity, resistance to corrosion, high mechanical resistance, and biocompatibility.[6,7] Currently, there are four commercially pure Ti grades and one alloy that are used for manufacturing of dental implants (Table 1). Although for a few years low-temperature isotropic (LTI) carbon-coated implants showed greater potential for a long-term successful performance when compared to other substrate implants such as aluminum oxide substrates,[8] Ti implants have always demonstrated better biocompatibility results and a better long-term prognosis.[9,10] The same applies to implant surfaces coated with polymeric materials such as polymethyl methacrylate (PMMA) and polytetrafluoroethylene (PTFE) and carbon implants[9]; Ti-based implants remain the

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**Table 1** Grades of Titanium (Ti)*

| ASTM Grade | Type | Comments |
|---|---|---|
| Grade 1 | Unalloyed | Highest purity, lowest yield strength, lowest ultimate tensile strength, best room temperature ductility when compared to grades 2–4. High-impact toughness and good corrosion resistance. |
| Grade 2 | Unalloyed | Useful in chemical processes due to its high resistance to chemical environments, including oxidizing media, alkaline solutions, organic acids, aqueous salt solutions, and hot temperatures. |
| Grade 3 | Unalloyed | Its elastic modulus is similar to that of grades 1, 2, and 4. Can be considered as an intermediary material between the other grades. |
| Grade 4 | Unalloyed | Highest strength of the 4 unalloyed grades. |
| Grade 5 | Alloyed with 4% vanadium and 6% aluminum | Most commonly used grade of Ti alloy. Alpha-beta alloy with excellent yield strength, ultimate tensile strength, corrosion resistance, and fabricability. |

*From: Elias CN, Lima JHC, Valiev R, Meyers MA. Biomedical applications of titanium and its alloys. JOM 2008;60(3):47–49.

most widely used types of implants due to their outstanding properties and excellent long-term clinical results.[11]

The surface quality of dental implants has been subdivided into mechanical, topographical, and physicochemical properties.[5,12] The mechanical properties of an implant's surface are linked to the potential surface stresses and to the hardness of the material. The topographical features are linked to the irregularities present at the surface. The physical characteristics mainly focus on the surface energy and the charge present at the surface. It was concluded that a surface having a high surface energy had a higher adsorption affinity.[13]

Implant surfaces should be studied so as to determine the tissue reactions at the implant surface.[12] Albrektsson and Wennerberg classified implant surfaces as follows[12]:

1. Smooth surface with a surface roughness ($S_a$ < 0.5 μm)
2. Minimally rough surface ($S_a$ = 0.5–1 μm)
3. Moderately rough surface ($S_a$ = 1–2 μm)
4. Rough surface ($S_a$ > 2 μm)

From this review, the authors concluded that moderately roughened surfaces seem to have some clinical advantages over smoother or rougher surfaces. Still, the differences were small and often not considered to be statistically significant. Even though the moderately roughened surfaces showed a stronger osseous response over the other surfaces studied in vivo, bioactive implants have been claimed to show promising results as they provide both chemical and biomechanical anchorage. Two types of bioactive implants have been introduced: OsseoSpeed Biomanagement Complex Implant System (Dentsply) and calcium phosphate–coated implants.[12] These will be considered when discussing implant coatings in the following sections.

Although Ti implants have high clinical success rates,[1,9,11,14,15] coatings of various materials have been advocated.[16] An effective coating surface should be able to do the following: improve cell attachment, cell differentiation, and bone apposition; allow bone fixation; limit the rate of dissolution in the body fluids; and function in a therapeutic way.[9,10] When a Ti implant is coated, the implant coating material is sandwiched between the Ti implant and bone surfaces. The implant coating withstands all the forces it is subjected to while transferring all the loads imposed on the implant. The stress the implant-to-bone interface is subjected to is due to the difference in the modulus of elasticity between the prosthesis and the bone. If the stress is greater than the bonding strength, debonding or delamination of the coating can result.[9] Therefore, the thickness of the material coating the Ti core of the implant becomes an important parameter. By using calcium phosphate coatings, for example, it was demonstrated that ultrathin calcium phosphate coatings improved osseointegration, as opposed to a thick coating.[3] The thick coating prevented the adherence to the surrounding tissues while giving an internally weak structure that could eventually fracture and lead to implant failure.[3]

Different types of dental implant coating materials and coating techniques have been proposed. However, not all coatings provide the same properties to the prosthesis. Other reviews[11,12,16] focused on the effect of the loading and unloading of the implant while linking its effect on the bone integration system. This systematic review will link the conventionally used Ti implants to novel implant coatings and techniques.

Therefore, the aim of this literature review was to assess the diverse materials that have been used by various researchers as implant coatings and the coating techniques that have been employed.

## Materials and Methods

### *Selection of Papers*

This systematic review considered the question of whether currently popular Ti surfaces are the best solution one can offer to patients in dental implant therapy when compared to novel implant coatings and implant coating techniques.

**Types of participants.** The question being considered takes into account the different types of implant coatings when compared to the most commonly used Ti implants to determine their biocompatibility and osseointegrative potential.

**Types of intervention.** Trials comparing the different implant coating materials and implant coating techniques were taken into account. Even the most novel techniques and coatings were included even though not much long-term research has been provided.

**Types of outcome measures.** Osseointegration and biocompatibility were the main features that were looked for in the studies. Adverse events such as implant failure after loading and delamination also were considered from the articles reviewed.

**Types of studies.** Several in vitro and in vivo clinical studies were included in this review, along with with randomized controlled trials (RCTs), to give a better overall picture of the different types of implant coatings being introduced in dental implantology.

The review was performed using the Medline, Cochrane Library, and PubMed electronic databases as well as a manual search. In vitro and in vivo clinical studies together with RCTs were included in this review to give a better overall picture of the different types of implant coatings used in dental implantology. The keywords used in this literature review were "dental implant," "Ti dental implant," "osseointegration," "plasma-spraying," and "hydroxyapatite implant coatings." Articles that were not completely relevant to the aim of the literature review were excluded. The latter included studies that investigated the radiographic appearance of implants, corrosion potential of the implant core, and implants being inserted in other osseous structures in the human body. Osseointegration and biocompatibility were the main outcome measures that were examined in the studies. Adverse events such as implant failure after loading and delamination were also considered from the articles reviewed.

Papers were selected if they met the following criteria: evaluation of different types of dental implant coatings, osseointegration potential, implant coating techniques, and novel coatings compared with conventional Ti implants. The retrieved articles were first assessed by their titles and abstracts so as to exclude/include them in the review. The full-text versions of the relevant articles were then studied.

The database search strategy retrieved 320 articles with a hand search retrieving 30 articles. Search strategies were developed for each database used. These were mainly based on the MEDLINE search strategy while taking into account differences between vocabulary and syntax. The keywords were used in the search database separately and also combined together with AND or OR. Of the 350 articles, 195 articles were excluded as there was no reference to dentistry, only to orthopedic veterinary medicine or orthopedic surgery.

## Results

### *Systematic Review of the Literature*

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol was used to assess the criteria required for this review. A PRISMA flowchart showing the identification of data, screening, data eligibility, and inclusion can be seen in Fig 1.

### *Implant Coating Materials*

Several materials have been employed as coatings over dental implants made out of a core of Ti. These materials include carbon,[15–18] bisphosphonates,[19–22] bone stimulating factors,[23–27] bioactive glass and bioactive ceramics,[28–30] fluoride,[31] hydroxyapatite (HA) and calcium phosphate,[32–36] and Ti nitride (TiN).[37–41] The discussion of each coating follows, starting with the least common and most innovative proposed coatings and finishing with the most commonly used and quoted in the literature. Table 2 also will illustrate data on these implant coatings.

**Carbon coatings.** A total of four papers considered carbon coatings as a type of implant coating material. Two of the papers are systematic reviews including the other two papers mentioned. Thin carbon film with a chemical composition of $Ti_{0.5}O_{0.3}C_{0.2}$ has been used to coat Ti implants.[15,16] Carbon-coated implants were reported to give a good and stable chemical inertia between the carbon coating and the etching agent used. The carbon coatings were also found to be hemocompatible, histocompatible, biostable, and chemically stable in vitro and in vivo.[17] The corrosion resistance of the carbon coating could be improved by plasma immersion ion implantation and deposition or by direct carbon bonding. The surface properties together with the biologic properties were found to be improved by carbon plasma immersion ion implantation and deposition.[9,16] The direct carbon

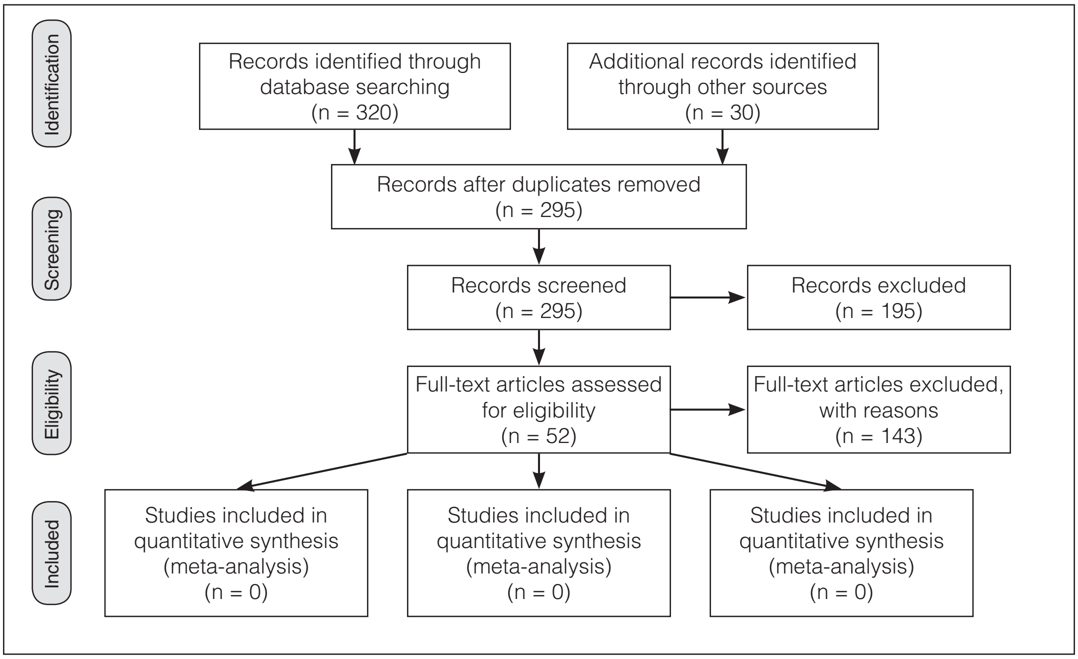


**Fig 1** 2009 PRISMA flow diagram—adapted from PRISMA 2009. From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6: e1000097. doi:10.1371/journal.pmed. 1000097.

bonding actually allows for osteoblast adhesion and proliferation at the surface of the nickel-titanium (NiTi) shape memory alloy.[18] Even though this seems to be a promising form of implant coating, not much long-term data could be found and most studies focused on other more innovative materials.

**Bisphosphonates.** Bisphosphonate coatings are another novel type of coating. Bisphosphonates have attracted studies in dentistry[19–22] due to their selective inhibition of osteoclasts, with a resultant net increase in bone quantity and net resultant change in osteoblastic activity. However, very few studies have supported the immersion of Ti implants in different types of bisphosphonates. Many of these studies are of short-term duration and are inconclusive, giving rise to several controversies. In a study by Yoshinari et al,[19] osteoblastic cell activity and inhibition effects were studied. Bisphosphonates immobilized on the surface of Ti implants investigated with calcium (Ca)-ion implantation and thin HA coatings provided a good osteogenic potential with no toxicity manifested on the osteoblasts.[19] Meraw et al[20] implanted different types of dental implants in dogs and after 28 days of implantation, bone-to-implant contact was investigated. The study was carried out over a period of 4 weeks with no long-term or clinical investigations available. Bone formation with the bisphosphonate pamidronate was greater than that with incadronate sodium. This same study concluded that incadronate sodium inhibits osteoclast activity more than pamidronate.[20] On the other hand, the bisphosphonate aledronate was found to increase the early bone formation rate around the dental implants in animal studies.[20] This increased bonelike nodules on the surface of the implant. The latter bisphosphonate was actually found to increase the size of the osteoclast cell to compensate for its inhibited activity. Therefore, the antiresorptive drug dose should be determined as well as the bone density surrounding the implant surface that is dependent on the bisphosphonate concentration.[20] Tyrosine phosphatase is one of the enzymes that plays an active role in the formation and functionality of osteoclasts and, therefore, is one of the main bisphosphonate targets.[21,22] The in vitro study by Goto et al[21] reported a method for measuring mineralized-tissue formation by cultured rat osteoblastic cells on Ti surfaces. Even though these studies have been performed, there still is some controversy with regard to the use of bisphosphonates as implant coatings. Although, for instance, the latter studies concluded that there was early bone formation around the prosthesis, one must still keep in mind that bisphosphonates act selectively as osteoclast inhibitors. Osseointegration is a dynamic process, dependent on osteoblastic and osteoclastic activity, and, therefore, by inhibiting the osteoclast activity, the long-term success of the implant may be compromised. In conclusion, the effect of bisphosphonates as an implant coating is still not known and further research is required prior to their investigation in a clinical study.

**Table 2** Summary of Implant Coatings

| Implant coating | Example | Studies | Outcome |
|---|---|---|---|
| Carbon coating[15–18] | Currently not on the market; still being investigated | In vitro, in vivo studies, and clinical studies | Improved biologic properties and histocompatibility but studies are still under way |
| Bisphosphonates[19–22] | Currently not on the market; still being investigated | No long-term studies available | No long-term studies available |
| Bone stimulating Factors[23–27] | Currently not on the market; still being investigated | Pilot animal studies and clinical studies | Studies are still under way |
| Bioactive glasses and ceramics[28–30] | Currently not on the market; still being investigated | Chemical, in vivo, and in vitro studies | Studies are still under way |
| Fluoride coatings[31] | OsseoSpeed | In vitro studies | Selective osteoblast differentiation results |
| Hydroxyapatite (HA)[32–36] | Restore Implant system | In vivo, in vitro, and retrieval studies | Most commonly used type of implant coating; other implant coating studies mainly use HA as a control |
| Titanium/titanium nitride[37–41] | IonFusion | In vitro, in vivo, and clinical studies | Titanium mechanical properties are considered in relation to the degree of osseointegration |

**Bone stimulating factors.** The coating of implants with bone stimulating factors (BSFs) is quite innovative and interesting. BSFs are very important during the osseointegration process, and by incorporating these components as coatings, the bone density in the peri-implant area, together with the prosthesis biocompatibility, can be improved. In one study, implants were also coated with growth factors so as to increase the bone healing potential after implant insertion. Implants coated in bone morphogenetic proteins (BMPs) can aid in achieving increased bond strength at the bone-implant surface when compared to controls without BMP-coated implants.[23] In another study, the use of the polylactide/glycolide (PLGA) polymer carrier with recombinant human BMP-2 showed a good healing potential and bone formation after 30 days but not after 90 days. Although growth factors enhance early bone healing, collagen coatings exhibit better results.[24] The use of insulinlike growth factors (IGFs), transforming growth factors, and platelet-derived growth factors (PDGFs) also have been considered as potential implant coatings to promote effective bone healing on insertion of an implant.[24] Due to the fact that the BSFs have to be released progressively in the peri-implant region, a plasmid containing the specific gene coding for a particular BMP has been considered. This proposal might cause an unwanted overproduction of the BSFs while also limiting the expression of the protein at the peri-implant site.[25] It has been hypothesized that Ti implants coated with BMP-2 can lead to increased bone formation around an implant.[26] With histophotometry, it was concluded that the coated implants led to an increased bone volume density after 1 month. Still, after 3 months the addition of the BMP-2 led to no increase in peri-implant bone formation even though the bone-to-implant contact had increased.[26] Another pilot animal study observed the amount of bone formed around implants coated with a combination of PDGF-B and IGFs.[27] After 7 days, there was an increased amount of bone present around the coated implant, but after 3 weeks there was no significant difference in the amount of the bone present around the coated implant and the control. The authors concluded that the amount of bone formed was practically the same but the growth factors increased the rate of bone formation at the peri-implant site.[27] In conclusion, BSFs are an innovative, promising coating as they offer both a healing potential after the surgical placement of the implant while giving rise to better osseointegration at the peri-implant site.

**Bioactive glass and bioactive ceramics.** Bioactive glasses and ceramics also have been proposed as good, innovative surface coatings for dental implants due to their glass properties, which would help obtain better implant osseointegration and reduced prosthetic corrosion in the body fluids.[9] The thermal expansion coefficients of the bioactive glasses and ceramics are usually much larger than those of Ti oxide. This thermal expansion can be reduced by increasing the silicon dioxide ($SiO_2$) content of the bioglass. On the other hand if the $SiO_2$ content is increased the bioactivity of the glass coating is reduced significantly.[28] The main disadvantage of these coatings is the limitation of use in load-bearing areas. Bioactive glass is actually a family of glass compositions that allow bonding to the peri-implant tissues within a short span of time. In a recent study, a reactive plasma spray bioactive glass coating was used to demonstrate the behavior of this type of surface coating in load-bearing situations.[29] It was concluded that a coating material can only be considered functional if it satisfies the following two criteria: *(1)* able to withstand the load-bearing forces imposed on them while *(2)* maintaining a strong bond with the implant surface to be totally functional. In vitro results showed that the bioactive glass satisfied both criteria even after a couple of months of load-bearing analyses.[29] It was also demonstrated that the silicate glasses have to have a weight percentage higher than 60% so as to be able to withstand corrosion and thermal expansion of the coating.[9] Silica contents above 60% weight would delaminate and crack. This can be circumvented by partial substitutions of calcium oxide (CaO) by magnesium oxide (MgO) and $Na_2O$ by potassium oxide ($K_2O$) in the bioglass composition to match the thermal expansion between the coatings and that of Ti-based alloys.[29] In another study, bioactive glasses were applied as a coating on Ti dental implants by an enameling technique with HA coatings acting as a control. Overall results showed that the bioactive glass coatings were as equally successful as HA coatings in achieving osseointegration and bioactivity.[30] Bioactive glasses and ceramics are a novel promising implant coating with clinical studies spanning over several months and even years.[30] This shows that the HA coatings are not the only implant coatings that give good osseoconduction. Still, several studies on bioglass need to be carried out to give further long-term results.

**Bioactive implant coatings.** OsseoSpeed (Dentsply) is a fluoride-modified nanostructure implant surface that is marketed to stimulate early bone formation. Fluoride ions are incorporated in the oxide layer of the prosthesis. In an in vitro study performed by Monjo et al,[31] the fluoride-coated implant was compared to TiOblast (Dentsply). The addition of fluoride was not found to affect the implant biocompatibility, but still it induced a more branched cellular morphology at the implant insertion site thus leading to a preferential osteoblastic differentiation.[31]

**Hydroxyapatite and other calcium phosphate coatings.** HA coatings have been afforded a substantial amount of importance due to the improved osteoconductivity they provide.[32–35] This type of coating material was actually introduced to combine the high metal strength with the good bioactivity of the calcium phosphate ($Ca_3(PO_4)_2$) compound.[9,25] Even though HA coatings have been studied extensively and indicated as one of the ideal implant coatings, their long-term prognosis is still controversial.[9] Investigation of the coating morphology, composition, and structure, together with any relevant changes occurring in the retrieved implant coatings, indicated that the thickness of the coating became thicker toward the apical portion of the implant, while lattice imperfections and changes in the composition were also noted. Even though these results were obtained, investigators could not relate these changes to implant failures in vivo.[32]

Cultures grown in HA gave an increased alkaline phosphatase expression and parathyroid hormone (PTH) response in the surrounding medium. In a similar scenario, the formation of the extracellular matrix was greater with $Ca_3(PO_4)_2$ coatings when compared to a bare Ti surface.[33,34] The use of $Ca_3(PO_4)_2$ as a coating material resulted in an increased resistance to shear forces created during implant insertion.[35] Iezzi et al[36] concluded that there was no inflammatory cell infiltrate present in the peri-implant tissues surrounding HA-coated Ti implants in a study that had an observation period of 14 years. This led to the conclusion that the HA coating may not be susceptible to the degradation or dissolution of the coating under long-term loading. Even though HA has been one of the most researched and investigated implant coatings, novel implant coatings can still give rise to promising results similar to those found for HA.

**Ti and TiN coatings.** The nitride compound exhibits similar properties to those of Ti.[37] Improved osseointegration was achieved by alteration of the TiN film thicknesses while also altering the surface topography of the coating, thus achieving a preferential neuronal response in relation to the nitrogen in the coating.[38] Nitride coatings were found to exhibit blood tolerability properties since exhibited protein absorption and platelet retention results were similar to those obtained with the control medical grade elastomer investigated.[39] Investigation of novel ways to control the surface oxidation of Ti revealed that although an oxide layer increases the bond strength, the very thick surface TiO layer results in a difficulty with the bonding process. It was demonstrated that TiN coatings can control the TiO layer formation and thus allow satisfactory bonding.[40] Another study discussed a novel way to coat Ti implants with TiN by using powder immersion reactions. This allowed for the establishment of a mechanically stable coating that improves the chemical and wear resistance of Ti. Scanning electron microscopy studies 2 months following implantation showed that both the coated and uncoated implants behaved similarly and underwent osseointegration to a comparable degree.[41] In this study, the Powder Immersion Reaction Assisted Coating method was used, whereby the substrate is directly involved in the formation of the coating layer, thus giving a good bond between the coating and the prosthesis.[41]

**[HB] implant coating techniques.** Implant coating techniques can be considered as important as the coating applied to the prosthesis. This is because the type of coating technique can result in either long-term success of an implant or else delamination and failure of the prosthesis. A description of the techniques proposed and studied is given below.

Precipitation and spray-drying process. HA granules with various structures including solid spheres and doughnut-shaped granules are produced by this method. This type of method was introduced by Luo and Nieh,[42] and it was concluded that doughnut-shaped HA particles, together with hollow and solid spheres, can be produced by altering the initial investigative parameters and slurry used. By reducing the granule size, one may provide a higher specific surface area, an increased bonding capacity, and increased mechanical properties resulting in an improved frictional force between the particles.[42,43]

**Plasma-spraying.** This is the most widely used technique for the commercial application of HA coatings to prosthetic implants. Even though it is the most widely used technique due to the tight adhesion between the implant surface and the coating, studies have shown that the coating is prone to adhesion failure and cracking.[44] Others have evaluated the elevated temperatures required during the coating process, which can cause detrimental effects on the prosthesis, including an alteration in the crystalline structure, the formation of a highly crystalline HA surface, and an eventual debonding of the coating.[45] Plasma-sprayed HA coating, which results in a minimal phase decomposition and high crystallinity without affecting the adhesive bond strength of the coating material, has been proposed. It was also found that disintegration of the surface coating occurred; this was mainly due to the excessive dissolution of the HA layer with amorphous $Ca_3(PO_4)_2$ formation and cracking of the coating.[46] The modulus of elasticity, stress, and strain; bonding strength; and microstructural analysis of such a coated implant were investigated in the presence of Hank's salt solution and also without being immersed in solution. It was concluded that all of the factors investigated deteriorated on insertion into the solution. This was mainly caused by the degraded cohesive bonding in the coating material due to an increased porosity.[47] From this, one may conclude that even though HA gives a promising bond with the Ti implant, the long-term properties of the material can alter from the initial ideal bonding to the eventual degradation of the cohesion.

**Hydrocoating techniques.** This is another way to coat Ti implants with an HA layer. Several hydrocoating techniques have been proposed. These include cathode electrolysis, electrophoresis, and the thermal substrate technique.[48] Because the latter two are single-step coating techniques, the HA is applied directly to the surface from solution. Hydroprocessing is used to coat complex-shaped substrates. This is used in such cases where high temperatures cannot be used but at the same time the collagen content and mass has to be studied closely.[48]

**Two-stage process.** This process involves microarc oxidation of Ti forming Ti films followed by UV-light illumination of the films in simulated body fluids. This technique was then further developed and improved into the sol-gel technique.[49] This more innovative method resulted in a coating having a good homogenous composition, low crystallization temperature, and fine grain size.[49,50] HA and fluor-HA films were deposited on a Ti substrate using the sol-gel technique. Various fluoride concentrations were incorporated into the HA structure during the sol phase preparation. The coating rate of dissolution decreased with increasing fluoride concentrations.[49] As expected, pure Ti implants gave less expression levels when compared to the activity present between the alkaline phosphatase and the apatite coatings.

**Nanoscale technology.** In a study by Jiang et al,[51] HA particles were charged as they were expelled from a powder spray gun while being exposed to an electrostatic field. The latter guided the charged particles toward the Ti to form a uniform coating. The coated Ti was then sintered in a microwave furnace. Nanoscale technology was found to give several benefits, including improved adhesion with decreased chances of delamination, increased surface areas for osseointegration, and improved implant-tissue integration together with a resulting chemistry mimicking that of natural osseous tissue.[51] This showed that this innovative technology can overcome the problems arising with other mentioned coating methods, thus improving the properties of the prosthesis.

**Titanium nitriding.** Several methods have been advocated to coat Ti implants with TiN, including physical vapor deposition, thermally applied coatings, and chemical vapor deposition.[52] The majority of coating methodologies are by physical vapor deposition. Even though much research has been performed to study the biocompatibility and mechanical properties of TiN coatings, very few clinical studies are available to improve the efficacy and effectiveness of this particular coating.[9,52]

## Discussion

Clinical success outcomes of osseointegration are in excess of 90%. Consequently, the aim of the studies discussed in this systematic review was to keep such a level with new coatings while giving more promising chemical and mechanical properties, hopefully resulting in more cost-effective outcomes. One may conclude that an implant coating can improve the properties of the implant while resulting in better physical properties and osseointegration. Even though several implant coatings have been proposed, some have been found to give better results than others. Even though the most commonly used and studied coatings are HA coatings, novel materials such as bioglass and carbon coatings are showing promising results. Furthermore, several different types and classes of materials are used in the different fields of dentistry. On the other hand, other coatings such as bisphosphonates seem promising in theory but have produced conflicting results. It may be presumed that materials serving the profession well in other fields of dentistry could be investigated in an attempt to propose more appropriate implant coating materials.

## Conclusions

Several materials have been proposed to coat dental implants. HA is the most commonly used one because of its biocompatible properties. Bioactive glasses and TiN coatings also show promise and may lead to osseointegration outcomes similar to those obtained with HA.

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*Literature Abstract*

**Does the presence or position of lower third molars alter the risk of mandibular angle or condylar fractures?**

This retrospective study of 446 patients with 731 mandibular fractures aimed to determine whether presence or absence of third molars and their angulation predisposed to either fractures of the angle or condyle. The average patient age was 29.3 years (± 11.3 years) with 84.5% males versus 15.5% females. The risk of angle fracture was significantly more likely to occur when an impacted third molar was present and the risk of condylar fracture significantly less likely to occur. The presence of normally erupted third molars was associated with significantly more angle fractures than those sides without any third molars. As the third molar occupies osseous space, it is thought that this results in a weakening due to reduction of bone volume. This study found no statistically significant association between angle of impaction and risk of fracture, although it might be thought that those impactions with discontinuity of the superior cortical border might have a greater incidence of angle fracture. It was hypothesized that the absence of third molars and, hence, a more robust angle will transmit applied force to the relatively weak condylar neck, resulting in its fracture. However, determining bone volume at the angle more accurately may be a better way to assess for risk of fracture in the presence of third molars.

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