Zirconia Dental Implants: A Literature Review

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Titanium and titanium alloys are widely used for fabrication of dental implants. Because of potential immunologic and possible esthetic compromises with titanium implants, novel implant technologies are being developed. However, these novel technologies must maintain the characteristics that provide titanium implants with their high success rates. Zirconia implants were introduced into dental implantology as an alternative to titanium implants. Zirconia seems to be a suitable implant material because of its toothlike color, mechanical properties, biocompatibility, and low plaque affinity. The aim of this study is to review clinical and research articles conducted on zirconia dental implants, compare them with titanium dental implants, and provide information on zirconia dental implant osseointegration and mechanical strength. Zirconia dental implants have the potential to become alternative dental implants to titanium dental implants, but they are not yet in routine clinical use.

Key Words: zirconia, dental, implant

INTRODUCTION

The rehabilitation of completely and partially edentulous patients with dental implants is a scientifically accepted and well documented treatment modality.[1] Currently, titanium and titanium alloys are the materials most often used in implant manufacturing and have become a gold standard for tooth replacement in dental implantology. These materials have attained mainstream use because of their excellent biocompatibility, favorable mechanical properties, and well documented beneficial results.[2,3] When exposed to air, titanium immediately develops a stable oxide layer, which forms the basis of its biocompatibility. The properties of the oxide layer are of great importance for the biological outcome of the osseointegration of titanium implants.[4]

The principal disadvantage of titanium is its dark grayish color, which often is visible through the peri-implant mucosa, therefore impairing esthetic outcomes in the presence of a thin mucosal biotype. Unfavorable soft tissue conditions or recision of the gingiva may lead to compromised esthetics. This is of great concern when the maxillary incisors are involved.[5] Furthermore, reports suggest that metals are able to induce a nonspecific immunomodulation and autoimmunity.[6] Galvanic side effects after contact with saliva and fluoride are also described.[7] Although allergic reactions to titanium are very rare, cellular sensitization has been demonstrated.[8,9]

Because of these disadvantages, novel implant technologies that produce ceramic

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DOI: 10.1563/AAID-JOI-D-09-00079

implants are being developed.[10] However, ceramics are known to be sensitive to shear and tensile loading, and surface flaws may lead to early failure. These realities imply a high risk for fracture.[11] In recent years, high-strength zirconia ceramics have become attractive as new materials for dental implants. They are considered to be inert in the body and exhibit minimal ion release compared with metallic implants. Yttrium-stabilized tetragonal zirconia polycrystals appear to offer advantages over aluminum oxide for dental implants because of their higher fracture resilience and higher flexural strength.[12] They have also been used successfully in orthopedic surgery to manufacture ball heads for total hip replacements; this is still the current main application of this biomaterial.[13,14] Zirconia seems to be a suitable dental implant material because of its toothlike color, mechanical properties, and therefore biocompatibility.[2] Apical bone loss and gingival recession associated with implants often uncover portions of the metal implant, revealing a bluish discoloration of the overlying gingiva. The use of zirconia implants avoids this complication and accedes to the request of many patients for metal-free implants. The material also provides high strength, fracture toughness, and biocompatibility.[14] The inflammatory response and bone resorption induced by ceramic particles are less than those induced by titanium particles, suggesting the biocompatibility of ceramics.[15,16]

Currently, 9 zirconia dental implant systems are commercially available. The Sigma implant (Sandhause, Incermed, Lausanne, Switzerland), which was developed in 1987, was the first zirconia dental implant system. Additional zirconia implant systems are the CeraRoot system (Oral Iceberg, Barcelona, Spain), the ReImplant system (ReImplant, Hagen, Germany), the White Sky system (Bredent Medical, Senden, Germany), the Goei system (Goei Inc, Akitsu-Hiroshima, Japan), the Konus system (Konus Dental, Bingen, Germany), the Z-systems (Z-systems, Konstanz, Germany), and the Ziterion system (Ziterion, Uffenheim, Germany).

Material composition and surface topography of a biomaterial play a fundamental role in osseointegration. According to Albrektsson et al, the quality of the implant surface is one major factor that influences wound healing at the implantation site and subsequently affects osseointegration.[17] Therefore, various chemical and physical surface modifications have been developed to improve osseous healing.[2] To improve surface properties, 2 main approaches may be used, such as optimizing the microroughness (sandblasting, acid-etching) or applying bioactive coatings (calcium phosphate, bisphosphonate, collagen).[18] The clinical use of zirconia dental implants is limited because fabrication of surface modifications is difficult, and smooth implant surfaces are not beneficial for osseointegration because of poor interaction with tissues.[19]

Although zirconia may be used as an implant material by itself, zirconia particles are also used as a coating material of titanium dental implants. A sandblasting process with round zirconia particles may be an alternative surface treatment to enhance the osseointegration of titanium implants.

Many research articles have been written about zirconia dental implants. Thus, the purpose of this review is to summarize research articles conducted on zirconia dental implants, compare them with titanium dental implants, and provide information on zirconia dental implant osseointegration.

Materials and Methods

This review started with a PubMed search from 1975 to 2009. The search was conducted using the following key words: *zirconia* or *zirconium dioxide*, *dental*, and *implant*. The full text of articles was obtained where

possible. If it was not possible to obtain a full text, the electronically available abstracts were collected. Thus, the inclusion criteria for articles were as follows: (1) Articles were related to zirconia dental implants, and (2) abstracts were obtained when the full texts could not be obtained. Articles about zirconia implants for orthopedic usage were excluded from the review.

Results

The PubMed search resulted in 108 articles. The total number of papers that met the inclusion criteria for this review was 37. Of these, 30 were laboratory studies, 3 were clinical studies, 2 were case reports, and 2 were review articles.

Most of the studies were conducted in vitro.[1,2,11,18,20–45] Osseointegration and bone-implant contact (BIC) were investigated in 18 articles,[2,18,20–35] surface analyses in 4 articles,[1,36–38] removal torque testing (RTQ) in 4 studies,[1,39–41] mechanical strength in 4 articles,[11,42–44] and stress analyses in 1 article.[45] Three clinical studies involved clinical survival rate.[46–48] Other published articles were case reports[49,50] and reviews.[51,52]

1. Osseointegration, histologic analyses, and BIC

Eighteen articles discussed osseous healing, histologic analyses, and BIC of zirconia dental implants.[2,18,20–35] Seven of these articles evaluated zirconia as a coating material,[20–26] and 11 evaluated zirconia dental implants.[2,18,27–35]

Zirconia as a Coating Material

Cranin et al[20] investigated the osseointegration of vitallium implants with the addition of ceramic coatings, such as alumina (n 5 9) or zirconia (n 5 9). All alumina-coated vitallium implants and 5 of the zirconia-coated vitallium implants failed after 32 weeks. Investigators concluded that zirconia could be considered a superior ceramic coating to alumina. Nordlund et al[21] studied the tissue integration of 3 types of implant materials in monkeys: (1) alumina with 4% zirconia and 25% magnesia, (2) alumina with 25% silicon carbide, and (3) unalloyed titanium implants. No difference in tissue reaction around these 3 types of implant materials was observed after 6–8 months.

Franchi et al[22] evaluated peri-implant tissues of zirconia-coated titanium implants and acid-etched titanium implants by light microscopy. All implants showed new bone trabeculae, vascularized medullary spaces, and close contact with preexisting bone at 2 weeks. Franchi et al[23] also evaluated in an animal study peri-implanted tissues for titanium implants with different surfaces—smooth, titanium plasma sprayed, and zirconia blasted. At 3 months, it was observed that implant surface morphology strongly influenced the rate and the modality of peri-implant osteogenesis. Rough surfaces and in particular zirconia-blasted implants seemed to favor bone deposition on the titanium surface. In another study, the same group[24] investigated peri-implant osteogenesis and biologic fixation for various zirconia sand-blasted titanium implant surfaces and a machined titanium surface. The highest values for BIC, bone ingrowth, and Vickers hardness were measured in implants sand-blasted with zirconia particles, which have higher surface roughness (arithmetical mean roughness [Ra]: 1.52 μm, maximum peak [Rt]: 12.06 μm, and ten-point mean roughness [Rz]: 11.54 μm), followed by zirconia sand-blasted implants with lower surface roughness (Ra: 1.32 μm, Rt: 8.76 μm, and Rz: 8.86 μm).

Sollazo et al[25] observed titanium implant surfaces coated with zirconia, which can potentially have specific biologic effects. The BIC percentage was 31.8 6 3.05% for uncoated titanium implants and 43.8 6 2.05% for titanium implants coated with

zirconia at 4 weeks. It was found that zirconia coating would enhance implant osseointegration. Bacchelli et al[26] examined peri-implant osseointegration and found the following: Machined titanium implants had 34.5% BIC, titanium plasma-sprayed titanium implants had 44.7% BIC, alumina-blasted titanium implants had 53.4% BIC, and zirconia-blasted titanium implants had 35.5% BIC at 2 weeks. This was the only study that found zirconia coating was not superior to the other groups; this finding may be attributed to short evaluation time (2 weeks).

Zirconia as an Implant

Akagawa et al[27] examined the initial implant-bone interface with the 1-stage zirconia screw implant (Goei Industry, Akitsu-Hiroshima, Japan) with different occlusal loading conditions after 3 months in beagle dogs. In the nonloaded group, no superstructure was seen; the loaded group had metal superstructures. At 3 months, no significant difference was noted for BIC between the 2 groups. The BIC was 81.9% for the nonloaded group and 69.8% for the loaded group. The same researchers[28] observed the role of osseointegration around the 1-stage zirconia screw implant (Goei) with various conditions for loading support after 2 years of function in monkeys. Three types of superstructure were provided in each animal to obtain different concepts of support: (1) single freestanding implants, (2) connected freestanding implants, and (3) a combination of implant and tooth. Clinically, all implants were immobile for 24-month loading, and healthy peri-implant mucosa was achieved in the single freestanding, connected freestanding, and implant-tooth support groups, with favorable values for clinical parameters. Histologically, the direct bone-implant interface was generally attained in all observed zirconia implants.

Dubruille et al[29] compared the BIC on 3 types of dental implants: titanium, alumina, and zirconia (Sigma, Lausanne, Switzerland); these were placed into the dog mandible. At 10 months, BIC was found to be 68% for alumina, 64.6% for zirconia, and 54% for titanium. No statistically significant difference was noted between the 3 types of implants. Scarano et al[30] demonstrated the bone response to zirconia implants at 4 weeks. A great quantity of newly formed bone was observed with zirconia surfaces, and the percentage of BIC was 68.4%. These studies concluded that zirconia implants are highly biocompatible and osteoconductive.

Mosgau et al[31] evaluated the BIC of zirconia endodontic endosseous cones in apicectomy. The ratio between the total cone/bone contact circumference (ram) and the total cone/fibrous tissue contact circumference (ram) was 0.95 on the titanium surface and 1.47 on the zirconia surface. This indicates that, proportionately speaking, significantly greater bony healing was seen on the zirconia surface than on the titanium surface.

Kohal et al[32] evaluated the soft and hard tissue conditions of sandblasted zirconia implants (Relmplant, Hagen, Germany) and compared them with sandblasted and acid-etched (SLA) titanium implants. The mean mineralized BIC achieved after 9 months of healing and 5 months of loading was 72.9% for titanium implants and 67.4% for zirconia implants.

Hoffmann et al[33] histologically assessed the degree of early bone apposition around zirconia dental implants (Z-system, Konstanz, Germany) at 2 and 4 weeks following insertion. The zirconia implants demonstrated a slightly higher degree of bone apposition (54%–55%) compared with the titanium implants (42%–52%) at the 2-week time point, but bone apposition was higher in titanium (68%–91%) than in zirconia (62%–80%) at 4 weeks.

Langhoff et al[18] compared the BIC of chemically modified (plasma-anodized or

coated with calcium phosphate) titanium implants, pharmacologically coated (bisphosphonate or collagen type I with chondroitin sulphate) titanium implants, SLA titanium implants, and SLA zirconia implants. The zirconia implants presented 20% more bone contact than the titanium implants at 2 weeks, improved toward 4 weeks, then were reduced at 8 weeks. Although statistically not significant, a clear tendency was noted for the chemically and pharmacologically modified implants to show better BIC values at 8 weeks compared with the anodic plasma treated-surface of zirconia implants. All titanium implants had similar BIC at 2 weeks (57%–61%); only zirconia was found to be better (77%).

In a study conducted by Deprich et al,[34] 24 screw-type zirconia implants (Konus Dental, Bingen, Germany) with acid-etched surfaces were compared with 24 implants of commercially pure titanium with acid-etched surfaces. At 12 weeks, ultrastructural evidence of successful osseointegration of both implant systems was found. No significant differences in strength and stiffness of attachment between the 2 implant designs were detected at this time point. The same researchers compared osteoblast behavior on structured zirconia (Konus) and titanium surfaces in another study.[35] Attachment kinetics, proliferation rate, and synthesis of bone-associated proteins on both surfaces were examined and compared. At day 1, cell proliferation of zirconia surfaces was similar to that of titanium surfaces. At day 3, cell growth was significantly higher on the zirconia surfaces than on the titanium surfaces. At day 5, cell proliferation continued to be significantly higher on zirconia surfaces than on titanium surfaces. In the last study conducted by this group,[2] the osseous healing of zirconia implants (Konus) was compared with that of acid-etched titanium implants with the same macroscopic design in an animal experiment. At 1, 4, or 12 weeks, BIC was slightly better on titanium than on zirconia surfaces. However, a statistically significant difference between the 2 groups was not observed. Results demonstrated that zirconia implants with modified surfaces resulted in an osseointegration that was comparable with that of titanium implants.

2. Surface analyses

Surface analyses were performed in 4 studies.[1,36–38] In the first study, Yang et al[36] investigated zirconia with 4% CeO_2 and zirconia with 3% Y_2O_3 coatings, which were deposited on titanium and CoCrMo implants using the plasma spraying technique. Adhesive, morphologic, and structural properties of the plasma-sprayed coatings were evaluated. The average surface roughness of zirconia with 3% Y_2O_3 and of zirconia with 4% CeO_2 was correlated with the starting powder size and substrates. The size of zirconia with 3% Y_2O_3 powders was 40–100 μm, and the size of zirconia with 4% CeO_2 powders was 10–20 nm. No significant difference was observed between the hardness of all coatings and substrates. The adhesive strength of zirconia with 4% CeO_2 coating to titanium and CoCrMo substrates was higher than 68 MPa and significantly greater than that of zirconia with 3% Y_2O_3 coatings (32.3 MPa for titanium and 24.7 MPa for CoCrMo).

In the other study,[37] machined zirconia, sandblasted zirconia, and SLA zirconia surfaces were evaluated. The surface roughness of zirconia was increased by airborne particle abrasion and additionally by acid-etching. Cell proliferation revealed statistically significant greater values at 3 days for surface-treated zirconia as compared with machined zirconia. However, no differences were observed between the zirconia groups and SLA titanium at 6 and 12 days.

In another study,[1] Gahlert et al examined zirconia implants with a machined or a sandblasted surface and compared them

with SLA titanium implants. Surface analyses revealed that the highest surface roughness was measured for the SLA titanium implant, followed by the sandblasted zirconia implant and the machined zirconia implant. In the last study conducted by Stübinger et al,[38] the influence of erbium-doped yttrium aluminium garnet (Er:YAG), carbon dioxide (CO_2), and diode laser irradiation on surface properties of polished zirconia implants was evaluated. SEM analyses demonstrated that diode and Er:YAG lasers did not cause any visible surface alterations. However, the CO_2 laser produced distinct surface alterations to zirconia.

3. RTQ (removal torque testing)

Sennerby et al[39] observed bone tissue responses to machined and surface-modified zirconia implants. To achieve a porous surface, the zirconia implants were coated with 2 different slurries containing zirconia powder and a pore-former, which gave different surface structures. Noncoated zirconia implants were used as controls. In addition, titanium implants were used. The coated zirconia implants and the titanium implants showed higher RTQ than the machined zirconia implants.

Gahlert et al[1] evaluated the RTQ values of machined zirconia implants, sandblasted zirconia implants, and SLA titanium implants. The machined zirconia implants showed statistically significant lower RTQ values than the other 2 implant types after 8 and 12 weeks, and the SLA titanium implant showed significantly higher RTQ values than the sandblasted zirconia surface at 8 weeks. The mean RTQ for machined zirconia implants was 25.9 N/cm, the mean RTQ for zirconia rough implants was 40.5 N/cm, and the mean RTQ for SLA titanium implants was 105.2 N/cm.

Alzubaydi et al[40] evaluated the effects of ceramic coatings (hydroxyapatite and zirconia) on the bond strength between bone and implant, as well as the cell compatibility of screw-shaped titanium dental implants. Biomechanical testing was carried out at 2, 6, and 18 weeks healing time points. An increase in RTQ values was noted in the bone-implant interface with time, and the highest increment in bond strength was recorded for implants coated with 50% hydroxyapatite and 50% zirconia. The interface reaction of bone toward coated implants was faster than toward uncoated ones.

Ferguson et al[41] compared the biomechanical properties of 6 types of implant surfaces and found the RTQ values of SLA titanium as 1884 N/mm, SLA and calcium phosphate (CaP)-coated titanium as 1683 N/mm, SLA and anodic plasma chemical surface-treated titanium as 919 N/mm, SLA and bisphosphonate-coated titanium as 1835 N/mm, SLA and collagen-coated titanium as 1593 N/mm, and SLA zirconia as 1005 N/mm. At 8 weeks, RTQ values of zirconia were significantly lower.

4. Strength

Minamizato et al[42] investigated the compressive strength of the blade type of zirconia dental implants with tunnels drilled by laser process, and found that specimens with tunnels showed lower compressive strength (237 kg/mm^2) than specimens without tunnels (371.5 kg/mm^2). They concluded that zirconia blades had adequate strength in occlusion.

Kohal et al[43] evaluated the fracture strength of titanium implants with metal-ceramic crowns, zirconia implants with Empress I crowns, and zirconia implants with Procera (Al_2O_3 based) crowns before and after exposure to the artificial mouth. In the nonloaded group, fracture strength was 531.4 N for titanium, 512.9 N for zirconia-Empress I, and 575.7 N for zirconia-Procera. After a chewing load of 1.2 million cycles, fracture strength was 668.6 N for titanium,

410.7 N for zirconia-Empress I, and 555.5 N for zirconia-Procera. Fracture values for metal-ceramic and Procera crowns after artificial loading were significantly higher than for the loaded Empress I crowns. Zirconia implants restored with the Procera crowns possibly fulfill the biomechanical requirements for anterior teeth.

Silva et al[44] examined the effects of full crown preparation on the reliability of the 1-piece zirconia implant. They found that the fracture strength of zirconia implants without preparation was 1023.3 N, and with full crown preparation was 1111.7 N. However, in another study, it was concluded that preparation of the implant heads had a significantly negative influence on implant fracture strength.[11] Investigators evaluated the fracture strength of 1-piece zirconia implants (Sigma) after exposure to the artificial mouth, where a clinical service of 5 years was simulated. Zirconia implant fracture occurred at 725 to 850 N when the implant heads were not prepared, and at 539 to 607 N when prepared. They concluded that the mean fracture strength of zirconia implants ranged within the limits of clinical acceptance.

5. Stress analysis

One study evaluated stress analysis. Kohal et al[45] observed the stress distribution patterns of zirconia implants (ReImplant), which were found to have low, well distributed, and similar stress distribution compared with titanium implants. These patterns could be characterized as favorable or nondestructive. Stress values were found to be similar for both models for all regions.

6. Clinical studies

Three clinical studies investigated zirconia implants. Blaschke et al[46] reported that dental implants made from zirconia are a feasible alternative to titanium dental implants. In addition to excellent cosmetic results, zirconia implants allow a degree of osseointegration and soft tissue response that is superior to that of titanium dental implants. Oliva et al[47] reported the first clinical evaluation of 100 zirconia implants (CeraRoot, Barcelona, Spain) with 2 different surface roughnesses in humans after 1 year of follow-up. Two implants failed after 15 days. These failed implants were placed in situations where sinus elevation was required. The overall success rate was reported as 98%. Given the sinus elevation requirement, future investigators may exclude patients with less than 5 mm residual bone. Pirker et al[48] placed a zirconia implant to the maxillary first premolar region immediately and evaluated the clinical outcome of this implant. At 2-year follow-up, a stable implant and an unchanged peri-implant marginal bone level were observed. No bleeding was detected on probing.

7. Case reports

Kohal et al[49] presented the first clinical case report of a zirconia dental implant in the literature. A custom-made 2-piece zirconia implant was used to replace a left upper central incisor with zirconia abutment and a zirconia-based single crown. Furthermore, Oliva et al[50] reported the first clinical case of an ovoid zirconia dental implant. An anatomically oriented ovoid zirconia implant (CeraRoot Type 14), which was specially designed to replace a missing premolar, was discussed.

Conclusion

On the basis of available peer-reviewed data, osseointegration of zirconia dental implants may be comparable with that of titanium implants. They were also found to have low, well distributed, and similar stress distribution when compared with titanium implants. Furthermore, zirconia particles used for surface modifications of titanium implants may have the potential to improve initial

TABLE 1
In vitro studies examining bone-implant contact of different implants

Investigator	Type of Implant	Follow-up Period	Bone-Implant Contact, %
Akagawa, 1993	Nonloaded zirconia	3 mo	81.9
	Loaded zirconia	3 mo	69.8
Dubruille, 1999	Titanium	10 mo	54
	Alumina	10 mo	68
	Zirconia	10 mo	64.6
Scarano, 2003	Zirconia	4 wk	68.4
Kohal, 2004	Sandblasted zirconia	14 mo	67.4
	Sandblasted titanium	14 mo	72.9
Hoffmann, 2008	Titanium	2 wk	42–52
	Zirconia	2 wk	54–55
	Titanium	4 wk	68–91
	Zirconia	4 wk	62–80
Sollazzo, 2008	Titanium	4 wk	31.8
	Zirconia-coated titanium	4 wk	43.8
Bacchelli, 2009	Machined titanium	2 wk	34.5
	Titanium plasma-sprayed titanium	2 wk	44.7
	Aluminum-blasted titanium	2 wk	53.4
	Zirconia-blasted titanium	2 wk	35.5

bone healing and resistance to removal of torque. The surface roughness of zirconia was found to be comparable with that of titanium implants. Although fabrication of surface modifications for zirconia is difficult, CO_2 lasers revealed distinct surface alterations to zirconia, and additional studies about this technique may help to improve surface roughness. Coated or surface-modified zirconia implants showed higher removal torque values than machined zirconia implants. To fulfill biomechanical requirements, restoring zirconia implants with high-strength ceramics or metal ceramics would be beneficial. Although a few short-term clinical reports are available and provide satisfactory results, controlled clinical trials with a follow-up of 5 years or longer should be performed to properly evaluate the clinical performance of zirconia implants and to recommend them for routine clinical use.

ABBREVIATIONS

BIC: bone-implant contact
CaP: calcium phosphate
CO_2: carbon dioxide

TABLE 2
Removal torque testing (RTQ) evaluation according to surface characteristic of implants

Investigator	Surface Characteristics of Implants*	Results of RTQ
Gahlert, 2007	Machined zirconia	25.9 N/cm
	Sandblasted zirconia	40.5 N/cm
	SLA titanium	105.2 N/cm
Sennerby, 2005	Machined zirconia	Significantly lower RTQ values
	Surface-coated zirconia	
	Titanium	
Ferguson, 2008	SLA titanium	1884 N/mm
	SLA + CaP-coated titanium	1683 N/mm
	SLA + anosdic plasma-treated titanium	919 N/mm
	SLA + bisphosphonate-coated titanium	1835 N/mm
	SLA + collagen-coated titanium	1593 N/mm
	SLA zirconia	1005 N/mm

*CaP indicates calcium phosphate; SLA, sandblasted and acid-etched.

Er:YAG: erbium-doped yttrium aluminium garnet
RTQ: removal torque testing
SLA: sandblasted and acid-etched

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