Review Article

Zirconia in dental implantology: A review

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Abstract

Background: Titanium has been the most popular material of choice for dental implantology over the past few decades. Its properties have been found to be most suitable for the success of implant treatment. But recently, zirconia is slowly emerging as one of the materials which might replace the gold standard of dental implant, i.e., titanium. **Materials and Methods:** Literature was searched to retrieve information about zirconia dental implant and studies were critically analyzed. PubMed database was searched for information about zirconia dental implant regarding mechanical properties, osseointegration, surface roughness, biocompatibility, and soft tissue health around it. The literature search was limited to English language articles published from 1975 to 2015. **Results:** A total of 45 papers met the inclusion criteria for this review, among the relevant search in the database. **Conclusion:** Literature search showed that some of the properties of zirconia seem to be suitable for making it an ideal dental implant, such as biocompatibility, osseointegration, favourable soft tissue response and aesthetics due to light transmission and its color. At the same time, some studies also point out its drawbacks. It was also found that most of the studies on zirconia dental implants are short-term studies and there is a need for more long-term clinical trials to prove that zirconia is worth enough to replace titanium as a biomaterial in dental implantology.

Key words: *Biocompatibility, mechanical properties, osseointegration, surface roughening, titanium dental implant, zirconia, zirconia and biocompatibility, zirconia and implant surface coating, zirconia and osseointegration, zirconia dental implant*

INTRODUCTION

Dental implants have improved the quality of life for many patients.[1] Currently titanium and titanium alloys are most widely used as dental implants due to their excellent biocompatibility, good mechanical properties, and long term follow-up in clinical success.[2,3] Even though titanium is a popular material, it has certain disadvantages such as greyish color, which is unaesthetic, especially in the anterior region where the gingival tissue is considerably thin.[4] Some studies have also reported of galvanic reaction that occurs after it comes in contact with saliva and fluoride.[5] Inflammatory response and bone resorption were also found to be induced due to titanium particles.[6]

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In the last few years, zirconia dental implant has emerged as an alternative for titanium implant due to its potential to osseointegrate[7-9] and having other beneficial properties like its translucency and white color which mimics the natural teeth.[10,11] It is radiopaque similar to titanium and can be easily visualized on the radiograph.[12] Bacterial colonization around zirconia is found to be less as compared to that with titanium.[13] Some studies have reported that zirconia has more biocompatibility as compared to titanium, as the latter produces corrosion products at the implant site.[5]

This review of literature aims to discuss various properties of zirconia like osseointegration, biocompatibility, and less bacterial colonization, which make it a biomaterial suitable to be used as dental implant, and tries to find out whether the researches done till date authenticate its use.

MATERIALS AND METHODS

Literature search was done from 1975 to 2015 in PubMed database regarding mechanical properties, osseointegration, biocompatibility, soft tissue response, and antibacterial adhesion properties of zirconia. Literature search was only limited to English language articles. Keywords used in literature search were Zirconia Dental Implant, Zirconia AND Osseointegration, Zirconia AND soft tissue response, Zirconia AND Biocompatibility. Abstract were screened and full texts of potentially eligible articles were obtained. All articles on surface coating of zirconia on implant surfaces, are excluded from the review.

A total of 45 papers met the inclusion criteria for the review. All of these papers included *in-vitro* studies, in-vivo studies and case reports. Results of the literature search were discussed under different sections.

Mechanical properties of zirconia implants

Yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) materials exhibit superior corrosion and wear resistance, as well as a high flexural strength (800–1000 MPa) compared to other dental ceramics[14-17] [Table 1]. It was also found that flexural strength of zirconia increases by mechanical modification of its surface.[18] When the compressive strength of blade type of zirconia implants was tested, it was found to be adequate in occlusion.[19] Fracture strength (512.9 N) of unloaded zirconia was found to be more than the fracture strength (401.7 N) of loaded zirconia[20] [Table 1]. A study performed by Kohal *et al*. found low fracture strength of two-piece zirconia implants in both loaded and unloaded conditions, due to which they were not recommended for clinical use[21] [Table 1]. It was also found that the implant preparation and cyclic loading decrease the fracture strength of one-piece zirconia implants, but these values were still within clinically acceptable limits to withstand average occlusal forces even after an extended interval of artificial loading.[22] Whereas Silva *et al*. reported in their study that crown preparation had no influence on the reliability of one-piece ceramic implant[23] [Table 1].

ZrO_2 is a polymorphic material and occurs in three forms: Monoclinic, tetragonal, and cubic. The monoclinic phase is stable at room temperatures up to 1170°C, the tetragonal at temperatures of 1170–2370°C, and the cubic form at over 2370°C.[24,25] Alloying pure zirconia with stabilizing oxides, such as CaO, MgO, Y_2O_3, or CeO_2, allows the retention of the metastable tetragonal structure at room temperature. Dental procedures, such as grinding or sandblasting, can trigger a tetragonal to monoclinic transformation in the surface region.[15] Transformation from tetragonal phase to monoclinic phase is associated with volume expansion. This phase transformation results in compression of cracks, thereby retarding its growth and enhancing fracture toughness. This martensitic-like mechanism is known as transformation toughening.[26]

Due to severe environmental conditions of moisture and stress, the resulting zirconia may transform more aggressively to the monoclinic phase with catastrophic results. This type of high metastability is not good for dental implants. This mechanical property degradation in zirconia is known as "aging" of the material.[25] The transformation is enhanced in water or in vapor, while the most critical enhancing effects of temperature occur in the range of 200–300°C.[27,28] The transformation from tetragonal to monoclinic starts from surface and progresses to the core of the material. When the monoclinic phase dominates, it leads to reduction in strength, toughness, and density, which in turn leads to microcracking on the surface. This microcrack formation leads to penetration of water and causes corrosion.[27] Low temperature degradation of the material involves roughening, increased wear and microcracking, grain pull-out, generation of particle debris, and premature failure.[29] The aging process depends on various factors like porosity, residual stresses, grain size, and the content of stabilizer.[30] It was found that decrease in grain size and increase in stabilizing oxide content reduce the transformation rate.[28] Aging is accelerated due to changes in processing technique and can be avoided by more accurate processing.[27] Some *in vitro* studies have found that the aging reduces the mechanical properties of zirconia, even though within clinical acceptable limits, in simulated dental treatment conditions.[31,32]

Osseointegration of zirconia implants

One of the most important criteria for the success of implant treatment is osseointegration. Bone apposition takes place on different types of implant surfaces and depends on surface roughness of the implant.[33,34] Studies have shown that zirconia coating on the surface

Table 1: Mechanical properties of zirconia

Author	Materials	Parameters	Results
Kohal *et al*., 2006[20]	Titanium implants with Porcelain fused to metal crowns and zirconia implants with Empress-1 crowns and Procera crowns	Long-term fracture test was done on loaded and unloaded	Fracture strength (unloaded implant) Fracture strength (loaded implant) Zirconia 512.9 N 401.7 N Titanium 531.4 N 668.6 N
Chai *et al*., 2007[16]	Three zirconia-based dental ceramics: In-Ceram Zirconia (IZ), In-Ceram 2000 YZ CUBES (YZ Zirconia), and Cercon	Uniaxial flexural strength (UFS) and biaxial flexural strength (BFS)	For UFS YZ Zirconia (899±109 MPa) > Cercon (458±95 MPa) > IZ (409±60 MPa) > Empress-2 (252±36 MPa) For BFS YZ Zirconia (1107±116 MPa) > Cercon (927±146 MPa) > IZ (523±51 MPa) > Empress-2 (359±43 MPa)
Yilmaz *et al*., 2007[17]	Six ceramic core materials Finesse (F), Cergo (C), IPS Empress (E), In-Ceram Alumina (ICA), In-Ceram Zirconia (ICZ), and Cercon Zirconia (CZ)	Flexural strength, Weibull modulus, and fracture toughness	Mean (SD) of biaxial flexural strength values (MPa) and Weibull modulus (m) results were: Finesse (F): 88.04±31.61, m=3.17 Cergo (C): 94.97±13.62, m=7.94 IPS Empress (E): 101.18±13.49, m=10.13 In-Ceram Alumina (ICA): 341.80±61.13, m=6.96 In-Ceram Zirconia (ICZ): 541.80±61.10, m=10.17 Cercon Zirconia (CZ): 1140.89±121.33, m=13.26 Indentation fracture toughness Cercon Zirconia: 6.27 MPa (0.05) In-Ceram Zirconia: 5.58 MPa (0.18) In-Ceram Alumina: 4.78 MPa (0.18)
Silva *et al*., 2009[23]	One-piece Y-TZP ceramic implants	Specimens were step-stress fatigued until failure or survival	Crown preparation did not influence the reliability of the one-piece ceramic implant
Qeblawi *et al*., 2010[18]	Zirconia bars (4×5×40 mm) assigned to four groups: (1) control (no treatment), (2) airborne-particle abrasion (APA), (3) silicoating, and (4) wet hand grinding	Effect of mechanical surface treatment of yttria-partially stabilized zirconia on its flexural strength	Flexural strength in MPa Control: 571.7±79.2 APA: 798.8±138.2 Silicoated: 594.3±100.5 Hand ground: 1727.7±112.7

of titanium implants favours bone apposition,[35,36] which was found to be more than that of titanium implants with no coating.

Akagawa *et al*., in their study, found no significant difference in bone implant contact (BIC) between the loaded and unloaded zirconia implants. The BIC was 81.9% for the unloaded group and 69.8% for the loaded group[7] [Table 2].

Another study which examined the role of osseointegration around one-stage zirconia screw implant under various conditions for loading showed no difference in bone contact ratio among the single freestanding, connected freestanding, and implant-tooth supports of partially stabilized zirconia implants.[37] These findings were in agreement with another study which compared the BIC of submerged zirconia and non-submerged zirconia implants with submerged titanium as the control[38] [Table 2].

When BIC of zirconia implants was compared with that of titanium and alumina, there was no statistical difference between the BIC of all three types of implants.[39] Relatively bone healing around zirconia implants was found to be more than around titanium implants.[40] Some studies indicated that the zirconia implants might withstand occlusal loads over a longer period of time.[37,41]

Similar rate of bone apposition on zirconia and surface-modified titanium implant surfaces during early healing was found when a histological examination of early bone apposition around zirconia dental implants at 2 and 4 weeks after insertion was compared to that of surface-modified titanium implants.[42] There was no difference in osseointegration between acid-etched zirconia implants and acid-etched titanium implants.[43-45] This was true even when the implant surfaces were pharmacologically and chemically modified[46] [Table 2].

Surface roughness of zirconia implants

While direct bone apposition can occur on different types of surfaces, it has been demonstrated that a certain degree of surface roughness is beneficial in accelerating bone apposition to the implant surface.[33,34] Since

Table 2: Osseointegration of zirconia

Author	Material	Parameter	Result
Akagawa *et al*., 1993[7]	Partially stabilized zirconia endosseous implants under unloaded and early loaded conditions in four beagle dogs	Bone implant contact (BIC)	BIC (unloaded)=81.9% BIC (loaded)=69.8%
Akagawa *et al*., 1998[37]	Partially stabilized zirconia implants placed by a one-stage procedure on mandibles of eight monkeys	Bone implant contact (BIC)	Loading period: 12 months Single freestanding implants (4): 54-71% Connected freestanding implants (8): 58-77% Implant-tooth supported (4): 70-75% Loading period: 24 months Single freestanding implants (3): 66-81% Connected freestanding implants (6): 66-77% Implant-tooth supported (3): 66-82%
Dubruille *et al*., 1999[39]	Three types of dental implants (titanium, zirconia, or alumina) implanted in nine dogs	Bone implant contact (BIC)	Zirconia=65% Al2O3=68% Titanium=54%
Scarano *et al*., 2003[8]	Zirconia implants in white New Zealand rabbits	Bone implant contact (BIC)	Zirconia=68.4%
Schultze-Mosgau *et al*., 2000[40]	ZrO(2) cones and titanium cones in minipigs	Bone implant contact (BIC) Bone-fibrous connective tissue contact (BFCC)	BIC:BFCC ratio ZrO(2)=1.47±1.12 Titanium=0.19±1.10
Kohal *et al*., 2004[9]	Titanium implants (control group) and zirconia implants (test group) were inserted in the extraction sites in six monkeys	Bone implant contact (BIC) after 9 months of healing and 5 months of loading	Titanium=72.9±14 Zirconia=67.4±17
Hoffmann *et al*., 2008[42]	Titanium implants sandblasted and acid-etched, zirconia implants with roughened surface	Bone implant contact (BIC) at 2 and 4 weeks	2 weeks: Titanium=47.6% Zirconia=55% 4 weeks: Titanium=80% Zirconia=71.5%
Depprich *et al*., 2008[2]	Acid-etched zirconia implants and acid-etched titanium implants inserted in the tibia of minipigs	Bone implant contact (BIC) at 1, 4, and 12 weeks	1 week: Zirconia=35±11% Titanium=48±9% 4 weeks: Zirconia=45±16% Titanium=99±10% 12 weeks: Zirconia=71±18% Titanium=83±11%
Stadlinger *et al*., 2010[38]	One-piece zirconia implants and titanium implants inserted into the mandibles of minipigs Zirconia implants were alternatively submerged and non-submerged, but titanium implants were all submerged	Bone implant contact (BIC) and peri-implant bone volume density (rBVD)	BIC Submerged zirconia=53% Submerged titanium=53% Non-submerged zirconia=48% rBVD Submerged zirconia=80% Submerged titanium=74% Non-submerged zirconia=63%

Contd...

Table 2: Contd...

Author	Material	Parameter	Result
Gahlert *et al*., 2012[45]	Acid-etched zirconia implants, and sandblasted and acid-etched titanium implants inserted in miniature pigs	Bone implant contact (BIC) and peri-implant bone density values at 4, 8, and 12 weeks	BIC (range) Zirconia=67.1±21.1 and 70±14.5 Titanium=64.7±9.4 and 83.7±10.3 Peri-implant bone density 4 weeks Zirconia=60.4±9.9 Titanium=61.1±6.2 8 weeks Zirconia=65.4±13.8 Titanium=63.6±6.8 12 weeks Zirconia=63.3±21.5 Titanium=68.2±5.8
Kohal *et al*., 2013[69]	Four types of implant surface Titanium Titanium machined Sandblasted and acid-etched zirconia Machined zirconia	BIC	BIC (%) (SD) Day 14 Titanium=36.2±12.9 Titanium machined=23.2±6.3 Sandblasted and acid-etched Zirconia=17.6±1.4 Machined Zirconia=30.9±10.1 Day 28 Titanium=56.1±15.8 Titanium machined=39.4±3.9 Sandblasted and acid-etched Zirconia=33.5±4.1 Machined Zirconia=46.6±13.89
Gredes *et al*., 2014[70]	Newly created zirconia implant Standard zirconia implant and titanium implants	Bone implant contact (BIC) Biocompatibility	BIC Newly created zirconia implant 45% Standard zirconia 56% Titanium 35% Biocompatibility of zirconia was good in vivo, comparable to titanium

reduced treatment time is practiced more commonly in implant dentistry, the smooth surface of zirconia implants appears to be a disadvantage.[47] A study performed to investigate the osteoblastic response to Y-TZP with different surface topographies to increase the surface roughness by airborne particle abrasion and additionally acid etching showed cell proliferation with statistically significant higher values on day 3 for surface-treated zirconia as compared with machined zirconia. But no differences were found between the zirconia groups and sandblasted/acid-etched (SLA) titanium at 6 and 12 days.[48] It also found that roughening the zirconia implants enhances bone apposition and has a beneficial effect on the interfacial shear strength,[49] which was later contradicted by Hoffmann *et al*.[50]

High hardness of the zirconia implants makes the process of surface roughening very difficult. So, recently, laser has been used to engrave a pattern on the zirconia surface. A scanning electron microscopic (SEM) study done to find the influence of erbium-doped yttrium aluminium garnet (Er: YAG), carbon dioxide (CO_2), and diode laser irradiation on the surface properties of polished zirconia implants 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.[51]

Measurement of osseointegration

Torque removal forces have been used as a biomechanical measure of anchorage or osseointegration in which the greater forces required to remove implants may be interpreted as an increase in the strength of osseointegration.[52]

In the study of Sennerby *et al*., it was found that coated zirconia implants and titanium implants showed higher removal torque value than the machined zirconia implants. The findings suggested that surface-modified zirconia implants can reach firm stability in bone.[53] In another study wherein the removal torque values of machined zirconia implants, sandblasted zirconia implants, and acid-etched titanium implant were evaluated, machined zirconia had the least removal torque value. Acid-etched titanium implants had the highest removal torque value, followed by sandblasted zirconia implants. The findings suggest that sandblasted zirconia implants can achieve a higher stability in bone than machined zirconia implants.[49] Even when the zirconia was coated on titanium implants, it increased the removal torque value.[54] But in one of the studies that compared the biomechanical properties of six types of implant surfaces, it was found that removal torque value of zirconia implants was the least.[55]

It can be concluded that the removal of torque value of zirconia implants was improved after surface modification, but was not more than that of titanium implants.

Biocompatibility of zirconia implants

Various *in vitro* tests were conducted on osteoblasts, fibroblasts, lymphocytes, monocytes, and macrophages to test the biocompatibility of zirconia. It was observed that zirconia had no cytotoxic effect on osteoblasts and made the cells capable of elaborating the extracellular matrix by synthesizing various essential and structural proteins.[56] Zirconia does not induce pseudo-teratogenic effect, which makes it biocompatible.[57-59] Laser-modified zirconia showed better adhesion to osteoblasts due to the better wettability characteristics.[41] Zirconia does not provoke any inflammation pathway, as reported by Liagre *et al*.[60]

Wear products of zirconia could be cytotoxic as compared to titanium and other ceramics, when tested with fibroblasts.[61] But it was also noted that further studies are required to substantiate the evidence. Both powder and particles of zirconia tested *in vitro* on different cell lines (human and murine) of lymphocytes, monocytes, or macrophages did not induce high cytotoxicity or inflammation.[62]

Biocompatibility tests were also conducted *in vivo* for zirconia, and it was found that when it was implanted in the soft tissue, it became encapsulated by a thin layer of fibrous tissue similar to that seen in the case of alumina.[63,64] Also, there was no cytotoxicity in the soft tissue in relation to wear products of zirconia.[65] Zirconia was also found to be biocompatible to hard tissue when tested *in vivo* according to the findings of a study which inserted pellets of stabilized zirconia with 6% Y_2O_3 into the femur of monkeys.[66] When compared with alumina, zirconia showed no difference in bone reaction.[67,68] In the study by Kohal *et al*., it was found that cell proliferation around zirconia was comparable to titanium, but surface modification of zirconia did not show improvement in osseointegration.[69] Biocompatibility of zirconia was also found to be good in another study conducted by Gredes *et al*., in which they tested a newly created zirconia implant.[70]

Soft tissue response to zirconia implants

Studies conducted on the soft tissue response of zirconia implants [Table 3] have reported comparable findings for both zirconia and titanium. Tete *et al*. found that the collagen fiber orientation around zirconia implants was parallel to the implant surface, similar to that of titanium.[71] Brakel *et al*. reported that zirconia had similar probing depth as titanium.[72] Regarding the healing of soft tissue around the zirconia abutment and titanium abutment, it was reported by Wellander *et al*. that titanium had better soft tissue healing as compared to zirconia. The distance from the peri-implant mucosa to the apical termination of the barrier epithelium for zirconia was found to be less than that of titanium. The same study also found that zirconia had less mucosal color change as compared to titanium,[73] which was contradicted by Zembic *et al*.[74] Brakel *et al*. found no significant difference in the soft tissue response around zirconia and titanium abutments.[75] This finding was similar to the study finding of Kohal *et al*., wherein zirconia and titanium implants were inserted in the extraction sites of monkeys and both implants showed same peri-implant soft tissue dimensions.[9]

Bacterial colonization around zirconia implants

Bacterial colonisation is commonly found around the natural tooth due to humid environment and constant temperature inside the oral cavity.[76] Since the microflora around implants is similar to that of natural teeth, microbial pathogens (i.e. *Actinobacillus actinomycetemcomitans*, *Porphyromonas gingivalis*, or *Prevotella intermedia*) associated with periodontitis may contribute to implant failure.[76] When zirconia was introduced in orthopedics, some studies evaluated the adhesion of oral bacteria *in vitro*.[62] In a study which compared the inhibition of growth and adhesion of selected oral bacteria on titanium and zirconia, difference was found in the adhesion of some selected oral bacteria [Table 4]. But in an *in vivo* study, zirconia showed significantly lesser adhesion of bacteria than titanium,[13,77] which was contradicted

Table 3: Soft tissue response to zirconia implants

Author	Material	Parameters	Results			
Brakel *et al*., 2012[75]	Zirconia abutments Titanium abutments	Vascular density Inflammation grading scale		Vascular density	Inflammation grading scale	
			Zirconia	20.5±4.4	3.2±0.7	
			Titanium	20.7±3.2	3.1±0.7	
Brakel *et al*., 2011[72]	Grade 4 Ti screw implants and zirconia implants	Probing depth (PPD) Recession (REC), bleeding on probing (BOP)	Mean PPD	2 weeks	3 months	
			ZrO_2	3 (1.1)	1.7 (0.7)	
			Ti	2.9 (0.8)	2.2 (0.8)	
			Mean REC			
			ZrO_2	2.1 (1.2)	2.7 (0.6)	
			Ti	1.9 (1.2)	2.6 (1)	
			BOP			
			ZrO_2	50%	52.6%	
			Ti	75%	47.4%	
Tete *et al*., 2009[71]	Machined titanium implant neck Machined zirconia implant neck	Collagen fiber orientation Histological examination at epithelium-connective tissue junction		Collagen fiber	Gingival index	Probing depth
			Depth			
			Zirconia	48%	0-1	2 mm
			Titanium	58%	0-1	2 mm
Zembic *et al*., 2009[74]	Zirconia abutments and titanium abutments	Probing pocket depth (PPD), plaque control record (PCR), and bleeding on probing (BOP); and color difference (DE) in mucosa		Zirconia	Titanium	
			PPD	3.2±1	3.4±0.5	
			PCR	0.1±0.2	0.1±0.2	
			BOP	0.4±0.4	2.0±0.3	
			DE	9.3±3.8	6.8±3.8	
Welander *et al*., 2008[73]	Titanium abutment, zirconia abutment and Au/Pt-alloy abutments	Distance from peri-implant mucosa (PM) to the marginal level of bone to implant contact (B) and apical termination of the barrier epithelium (aJE) at 2 and 5 months		PM-B (2 months)	PM-aJE (2 months)	
			Zirconia	3.08±0.39	1.60±0.31	
			Titanium	3.13±0.33	1.80±0.29	
				PM-B (5 months)	PM-aJE (5 months)	
			Zirconia	2.82±0.39	1.60±0.31	
			Titanium	2.85±0.37	1.83±0.22	

Table 4: Bacterial colonization around zirconia implants

Author	Material	Parameter	Result			
Rimondini *et al*., 2002[13]	Disks of "as-fired" and "rectified" tetragonal zirconia polycrystals stabilized with yttrium (Y-TZP) and commercially pure grade 2 titanium	*In vitro*: Proliferation of bacteria: *Streptococcus mutans*, *Streptococcus sanguis*, *Actinomyces viscosus*, *Actinomyces naeslundii*, *and Porphyromonas gingivalis* *In vitro*: Early bacterial adhesion was evaluated in human volunteers	Bacteria	Y-TZP (nm)	Y-TZP (nm)	Ti (nm)
			S. mutans	0.48±0.02	0.27±0.01	0.33±0.01
			S. sanguis	0.09±0.0	10.13±0.01	0.18±0.01
			A. viscosus	0.15±0.01	0.14±0.01	0.16±0.01
			A. naeslundii	0.21±0.01	0.30±0.01	0.20±0.01
			P. gingivalis	0.08±0.02	0.09±0.00	0.11±0.01
			In vivo presence of cells on substrate			
			Bacteria	Y-TZP (nm)	Y-TZP (nm)	Ti (nm)
			Cocci	3.7±0.8	5.0±0.3	4.3±1.2
			Short rods	0.7±1.3	1.3±1.8	3.3±1.8
			Long rods	0.1±0.4	0.0±1.2	0.8±0.9
			Keratinocytes	0.8±0.9	1.0±0.6	0.1±0.0
Scarano *et al*., 2004[77]	Commercially pure titanium and zirconium oxide disks	Bacterial adhesion on titanium and zirconia disks		Percentage of disk covered by bacteria		
			Titanium	19.3±2.9%		
			Zirconia	12.1±1.96%		
Brakel *et al*., 2011[72]	ZrO_2 and Ti abutment surfaces	Early bacterial colonization		2 weeks	3 months	
			Summary	$\text{Ti} > \text{ZrO}_2$: 7	$\text{Ti} > \text{ZrO}_2$: 6	
			Statistic	$\text{Ti} < \text{ZrO}_2$: 10	$\text{Ti} < \text{ZrO}_2$: 11	

by Brakel *et al*. and Egawa *et al*., who reported that the bacterial adhesion of zirconia was similar to that of titanium.[72,78] With fewer studies on bacterial adhesion on zirconia surface, it can be concluded that plaque formation on this surface might be less.[72,79]

CONCLUSION

Limited amount of research on zirconia proves that zirconia is biocompatible with the surrounding tissues. Compared to titanium, its osseointegration is inferior and shows improvement after surface modification. Strength of zirconia is good, but comparatively lesser than that of titanium. Zirconia is osseoconductive as reported in some studies and has also shown favourable interaction with the soft tissue. It has been found that zirconia reduces plaque formation on the implant surface, which leads to good healing and successful implant treatment.

Most of the studies on zirconia implants are short-term studies and evidence of success in long-term clinical trials is lacking. More research is needed on zirconia dental implants before we could use it for frequent treatment needs, as compared to titanium implants.

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