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Dental implant material from titanium to zirconia - where are we now

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Abstract

Titanium and titanium alloys are extensively used for fabrication of dental implants. The material composition and the surface topography of a biomaterial play a critical role in osseointegration. Various physical and chemical surface modifications have been evolved to enhance osseous healing. Zirconia-based implants primarily were introduced into dental implantology as an alternative opportunity to titanium implants. Zirconia appears to be an appropriate implant material due to its tooth-like colour, its mechanical properties and its biocompatibility. The osseointegration of zirconia implants has now no longer been notably investigated, and the primary goal of this review is to compare the osseous healing of zirconia implants with titanium implants that have a roughened surface but otherwise comparable implant geometries. As an alternative to titanium implants, Zirconia implants have been familiarized into dental implantology. Zirconia seems to be an appropriate and best implant material because of its low plaque affinity, tooth like Color, biocompatibility and mechanical properties. Hence, Zirconia dental implants possess the potential and capacity to be an alternative to titanium dental implants.

Keywords: Mechanical properties, Surface roughness, Implant material, Zirconia and Osseointegration, Biocompatibility, Zirconia versus Titanium implant

Introduction

Dental implants have result in improvement in the quality of life for many patients. Currently titanium and titanium alloys are used broadly as dental implants because of their excellent and remarkable mechanical properties and biocompatibility, good mechanical properties, and long-term follow-up in clinical and scientific success[7].

In the previous years, zirconia dental implant emerged as an alternative opportunity for titanium implant because of its ability to Osseo integrate and different beneficial properties like its translucency and white Color which mimics the natural teeth. It is radiopaque as similar to titanium and can be easily visualized on the radiograph. Bacterial colonization around zirconia is determined to be less as compared to that with titanium. Some researchers have mentioned that zirconia has more biocompatibility compared to titanium, because the latter produces corrosion on the implant site[1].

Zircon has been known as a gem from historic times. The name of the metal, zirconium, comes from the Arabic phrase i.e. Zargon (golden in colour) which in turn comes from the two Persian phrase i.e. Zar (Gold) and Gun (Colour). Zirconia, the metal dioxide (ZrO_2), becomes identified in 1789 by the German chemist Martin Heinrich Klaproth in the reaction product obtained after heating a few gems, and become used for a long term mixed with an uncommon earth oxide as pigment for ceramics[2].

Although low-quality zirconia is used as an abrasive in huge quantities, wear resistant. Refractory zirconia ceramics are used to fabricate components which can be working in a competitive environment, which includes extrusion dyes, valves and port liners for combustion engines, low corrosion, thermal shock resistant refractory liners or valve parts in foundries. Zirconia blades are used to reduce Kevlar, magnetic tapes, cigarette filters because of their decreased wear. High temperature ionic conductivity makes zirconia ceramics appropriate which includes stable electrolytes in fuel cells as well as in oxygen sensors. Good chemical and dimensional stability, mechanical strength and toughness, coupled with a Young's modulus within side the equal order of magnitude of stainless-steel alloys becomes the initial point of the interest in using zirconia as a ceramic biomaterial[3].

The first paper regarding biomedical software of zirconia becomes published in **1969** by **Helmer and Driskell**, even the first paper regarding the use of zirconia to fabricate ball heads for Total Hip Replacements (THR), that is the current primary main application of this ceramic biomaterial, was introduced by **Christel et al[5].**

In the early stages of the development, numerous solid solutions had been examined for biomedical applications. But within the following years of the research efforts had been appeared to be an extra centred on zirconia—yttria ceramics that is characterised by fine grained microstructures known as Tetragonal Zirconia Polycrystals (TZP).

Nowadays, Tetragonal Zirconia Polycrystals (TZP) ceramics are the materials selected by almost all the manufacturers which might be introducing into the market place as zirconia ball heads (Standard ISO 13356). More than 300 000 TZP ball heads has been implanted, and most effective screw ups had been mentioned until now[6].

Historical Background Of Zirconia

Zirconia was originally discovered as a mineral in 1892, and has been widely used as a refractory material for applications such as the outer wall of space shuttles owing to its high melting point of 2,715°C. The most stable phase at ambient temperature is monoclinic, which, upon heating, transforms into tetragonal and cubic phases. However, when sintered zirconia is cooled to ambient temperature, cracks are formed in zirconia due to the volume increase from the tetragonal phase to the monoclinic phase, which decreases the mechanical strength of zirconia. The history of zirconia and its application to medicine and dentistry are summarized in Table1.

Table 1: Historical Background of Zirconia

Year	Material	Event And Application
1892	ZrO_2 mineral	Discovery
1929	Stabilized zirconia: Polycrystalline ceramics	Development
1937	Cubic zirconia in the form of microscopic grains	Development
1969	Application to medicine	First paper of zirconia for medical use
1973	Skull crucible process	Development
1975	Ceramic steel: Zirconia consisting of tetragonal phase within large cubic-phase grains (PSZ)	Development
1976	Commercial production	
1977	Y-TZP (Yttria-stabilized tetragonal zirconia polycrystalline)	Highest mechanical strength of 690MPa
1985	Y-TZP (Yttria-stabilized tetragonal zirconia polycrystalline)	Clinically marketed as the ball head of an artificial hip joint
2001	Marketed dental restoratives	CAD/CAM system, Dentsply Slrona
2005	Marketed dental restoratives in Japan	CAD/CAM system, Dentsply Slrona
2006	Zirconia implant	Abutment

Table 2: Historical Aspect of Titanium and Their Alloys

Year	Material	Event and application
1791	Ti element in ore	Discovery of malachite, ore of titanium
1795	Ti element in ore	Named as titan
1910	Ti	99.9% Ti is smelled by Hunter
1940	Ti	Confirmation of equivalent biocompatibility as stainless steel and cobalt-chromium alloy with animal test
1940	Ti	Success of smelting by Kroll process
1948	Ti	Launch of industrial production
1951	Ti	Confirmation of both soft and hard tissue compatibility with animal test
1957	Ti	Confirmation of non-toxicity with long term implantation
1959	Ti-Ni	Development of shape memory alloy in USA
1960	Ti	Excellent results in artificial joints
1960s	Ti	Marketing as surgical implants in UK and USA
1970s	Ti-6AL-4V	Diverting aircrafts materials to orthopaedic implants
1978	Ti-Cu-Ni	Trial of dental casting
1980	Ti-5Al-2.5Fe	Development in Europe

1982	Ti	Development of investment material and casting machine for dental casting
1985	Ti-6Al-7Nb0	Development in Switzerland
1993	Ti-12Mo-6Zr-2Fe	Development in USA
1993	Ti-13Nb-13Zr	Development in USA
1996	Ti-15Mo	Development in USA
1998	Ti-29Nb-13Ta-4.6Zr	Development in Japan
Around 2000	Ti-15Mo-5Zr-3Al	Development in Japan

Crystal Structure of Zirconia

Yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) materials exhibit superior corrosion, wear resistance, as well as a high flexural strength (800–1000 MPa) as compared to other dental ceramics[20] **[Table 3].**

It was observed that flexural strength of zirconia will increases by means of mechanical modification of its surface. When the compressive strength of blade type of zirconia implants was tested, it was observed that it was in an adequate occlusion. Fracture strength (512.9 N) of unloaded zirconia was found to have greater fracture strength (401.7 N) loaded zirconia[14] **[Table 3].**

A study performed by **Kohal et al. 2006** confirmed that low fracture strength of two-piece zirconia implants in each loaded and unloaded conditions, because of which they have been now no longer recommended for clinical use **[Table 3]**. In addition to this, it was also observed that the implant preparation and cyclic loading have been lower the fracture strength of one-piece zirconia implants, however these values have been were still within clinically applicable limits to withstand common occlusal forces, after a prolonged interval of artificial loading[23].

Silva et al. 2009 also reported that crown preparation have no impact on the reliability of one-piece ceramic implant **[Table 3].**

ZrO2 is a polymorphic material and occurs in three forms i.e. Monoclinic, tetragonal, and cubic. The monoclinic phase is stable at room temperatures as much as, the tetragonal is stable at temperatures of 1170– 2370°C, and the cubic is stable at over 2370°C. Alloying pure zirconia with stabilizing oxides, such as Cao, MgO, or CeO_2, allows the retention of the metastable tetragonal shape at room temperature. Dental procedures, along with grinding or sandblasting, can bring about a tetragonal to monoclinic transformation in the surface region. Transformation from tetragonal segment to monoclinic segment is related to volume expansion. This segment transformation outcomes in results in compression of cracks, thereby retarding its growth increasing and improving the fracture toughness. This martensitic-like mechanism is known as transformation toughening[22].

Due to intense environmental conditions of moisture and stress, the resulting zirconia can also additionally remodelled more aggressively to the monoclinic segment with catastrophic outcomes. This type of high metastability is not true for dental implants. This mechanical property degradation in zirconia is thought to be **"aging"** of the material[17]. The transformation is greater in water or in vapor, while the maximum critical enhancing effects of temperature occur in the range of 200–300°C. The transformation from tetragonal to monoclinic begins surface from surface and progresses to the middle core of the material. When the monoclinic segment dominates, it results in reduction in strength, toughness, and density, which in turn results in microcracking on the surface. This microcracking formation results in the penetration of water and causes corrosion. Low temperature degradation of the material involves roughening, increased wear and microcracking, grain pull-out, generation of particle debris, and premature failure.

The aging process relies on various factors such as porosity, residual stresses, grain size, and the content of stabilizer. It was observed that decrease in grain size and increase in stabilizing oxide content will lessen the transformation rate. Aging is increased because of modification in processing method and may be avoided by more accurate processing. Some in vitro studies reported that the aging reduces the mechanical properties of zirconia, despite within clinical acceptable limits, in simulated dental treatment conditions[10].

Table 3: Mechanical properties of Zirconia implants

Author	Materials	Parameters	Results
Kohal et al., 2006	Titanium implants with Porcelain fused to metal crowns and zirconia implants with Empress-1 crowns ana Procera crowns	Long- term fracture test was done on loaded and unloaded	Fracture strength (unloaded implant) Fracture strength (loaded implant)Zirconia 512.9 401.7NTitanium 531.4N 668.6N
Chai et al.,2007	Three zirconia-based dental ceramics: In- Ceram Zirconia (IZ). In-Ceram 2000 YZ CUBES (YZ Zirconia), and Cercone	Uniaxial flexural strength (UFS) and biaxial flexural strength (BFS)	For UFSYZ Zirconia > Cercone >IZ> Empress-2 For BFS YZ Zirconia> Cercone>IZ> Empress-2
Yilmaz et al.,2005	Six ceramic core materials Finesse(F), Cergo (C), IPS Empress (E), In-Ceram Alumina (ICA), In-Ceram Zirconia (ICZ), and Cercone 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): m=3.17Cergo (C): m=7.94IPS Empress (E): m=10.13In-Ceram Alumina (ICA): m=6.96In-Ceram Zirconia (ICZ): m=10.17Cercone Zirconia (CZ): m=13.26Indentation fracture toughnessCercone Zirconia:6.27MPa (0.05)In-Ceram Zirconia:5.58 MPa (0.18) In-Ceram Alumina: 4.78MPa (0.18)
Silva et al.,2009	One-piece Y-TZP ceramic	Specimens were step	Crown preparation did not

	implants	stress fatigued until failure or survival	influence the reliability of the one-piece ceramic implant
Qcbluwi et al., 2010	Zirconia bars assigned to four groups: 1) Control 2) Airborne- particle abrasion (APA) 3) Silicoating 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±198.2 Silicoated: 594.3±100.5 Hand ground: 1727.7±112.7

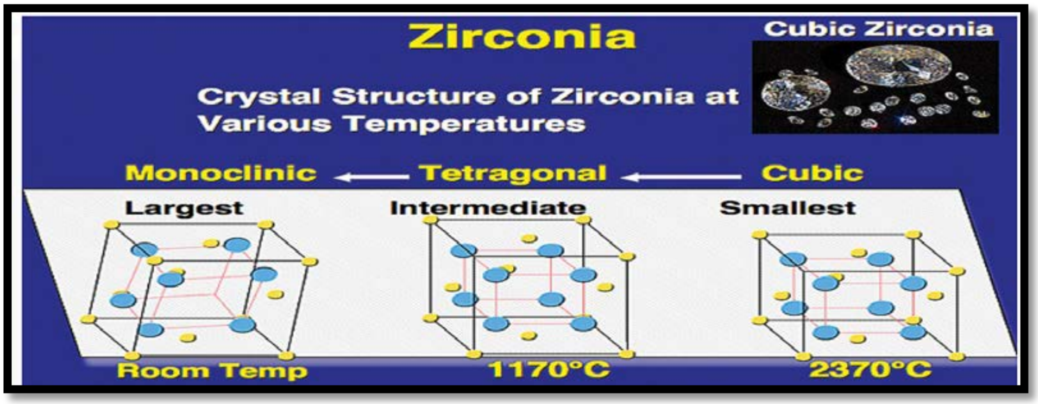


Fig 1: Phase transformation of pure ZrO_2 by temperature

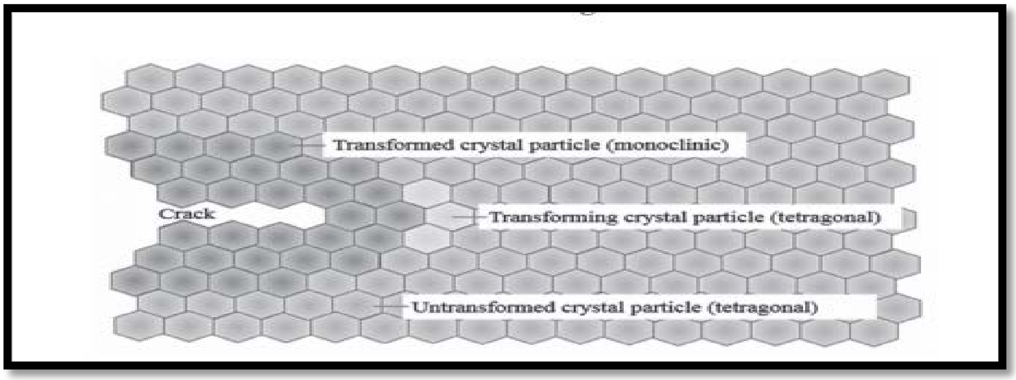


Fig 2: Stress induced transformation from tetragonal phase to monoclinic phase, generation resistance to micro-crack extension

Osseointegration of Zirconia Implant

One of the maximum essential criteria for the achievement of implant treatment is osseointegration. Bone apposition takes place on unique types of implant surfaces as it relies on the surface roughness of the implant. Studies have proven that zirconia coating on the surface of titanium implants favours bone apposition, which changed into observed to be more than that of titanium implants without coating[9].

Akagawa et al.,1993 in their study, observed no significant difference in bone implant contact (BIC) among the loaded and unloaded zirconia implants. The

Bone implant contact was 81.9% for the unloaded group and 69.8% for the loaded group[18] **[Table 4].** Another study which examined the role of osseointegration around one level zirconia screw implant below diverse situation for loading confirmed no difference in bone contact ratio among the single freestanding, linked freestanding, and implant-tooth supports of partially stabilized zirconia implants. These findings have been in agreement with another study when compared the Bone implant contact of submerged zirconia and non-submerged zirconia implants with submerged titanium as the control[8] **[Table 4].**

When Bone implant contact of zirconia implants was compared with that of titanium and alumina, there has been no statistical difference among the BIC of all three types of implants. Relatively bone healing around zirconia implants was observed to be more than around titanium implants[4]. Some research indicated that the zirconia implants would possibly resist occlusal loads over an extended duration of time. Bone apposition on zirconia and surface-modified titanium implant surfaces in the course of early healing was found while in 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. There was no difference in osseointegration among acid-etched zirconia implants and acid-etched titanium implants[11]. **[Table 4].**

Table 4: Osseointegration of Zirconia

Author	Material	Parameter	Results
Akagawa et al.,1993	Partially stabilized zirconia end osseous 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	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 monthsSingle freestanding implants (3) =66-81%Connected freestanding implants (6) = 66-77% Implant-tooth supported (3) =66-82%
Dubruille et al.,1999	Three types of dental implants implanted in nine dogs	Bone implant contact (BIC)	Zirconia=65% Al2O3=68% Titanium=54%
Scarano et al.,2000	Zirconia implants in white New Zealand rabbits	Bone implant contact (BIC)	Zirconia=68.4%

Schultze-Mosgan et al.,2000	ZrO cones and titanium cones in minipigs	Bone implant contact (BIC)	BIC-BFCC ratio ZrO =1.47 ±1.12
Kohal et al., 2001	Titanium implants and zirconia implants were inserted in the extraction sites in six monkeys	Bone implant contact (BIC) Bone-fibrous connective tissue contact (BFCC)	Titanium=72.9±14 Zirconia=67.4±17
Hoffmann et al., 2008	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=5.5% 4 Weeks: Titanium=80% Zirconia=71.5%
Depprich et al., 2008	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 Weeks: Zirconia=35±11% Titanium=18±9% 4 Weeks: Zirconia:4.5±16% Titanium:99±10% 12 Weeks: Zirconia:7.1±18% Titanium=8.3±11%
Stadlinger et al., 2010	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 density (rBVD)	BIC Submerged zirconia=53% Submerged titanium=48% rBVD Submerged zirconia=80% Submerged titanium=74% Non-submerged zirconia=63%
Gahlert et al., 2012	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 4,8, and12 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 = 6.54± 13.8 Titanium = 63.6± 6.8 12 Weeks Zirconia =63.3± 21.5 Titanium = 68.2 ± 5.8
Kohal et al., 2013	Four types of implant surface BIC 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 = 16.6± 13.89
Gredes et al.,2014	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 3.5% Biocompatibility of zirconia was good in vivo comparable to titanium

Bacterial Colonization around Zirconia Implants

Bacterial colonization is commonly found around the natural tooth which is due to humid environment and variation in constant temperature inside the oral cavity. The microflora around implants is similar to that of natural teeth, microbial pathogens i.e. Aggregatibacter actinomycetemcomitans, P. gingivalis, or P.intermedia are associated with periodontitis, they may also contribute to implant failure[10].

When zirconia was introduced in orthopaedics, many studies evaluated and observed the adhesion of oral bacteria in vitro. Study which compared the inhibition of growth and adhesion of selected oral bacteria on titanium and zirconia, difference was found only in the adhesion of some selected oral bacteria[13] **[Table 5].**

But in vivo study, zirconia showed significantly lesser adhesion of bacteria than titanium, which was contraindicated by **Brakel et al. 2011** reported that the bacterial adhesion of zirconia was similar to that of titanium.

Table 5: Bacterial Colonization around Zirconia Implant

Author	Material	Parameter	Results
Rimondini et al., 2002	Disks of 'as-fired' and 'rectified' tetragonal zirconia polycrystals stabilized with yttrium (Y-TZP) and commericially pure grade 2 titanium	In vitro: Proliferation of bacteria: S. mutan, S. sanguis, A. naeslundii, and P. gingivalis. In vitro: Early bacterial adhesion was evaluated in human volunteers	Bacteria S. mutans o.48± 0.02 S. sanguis 0.09 ±0.0 A. viscosus0.15 ±0.01 A. naeslundu 0.21±0.01 P. gingivalis 0.08±0.02 In vivo presence of cells on substrate Bacteria Cocci 3.7±0.8 Short rods 0.7±1.3 Long rods 0.1±0.4 Keratinocytes 0.8±0.9
Scarano et al., 2004	Commercially pure titanium and zirconium oxide disks	Bacterial adhesion on titanium and zirconia disks	Titanium 19.3±2.9% Zirconia 12.1± 1.96%
Brakel et al., 2011	ZrO2 and Ti abutment surfaces	Early bacterial colonization	Summary :Ti > ZrO2 Statistic Ti < ZrO2

Soft Tissue Response to Zirconia Implants

Studies conducted on the soft tissue response of zirconia implants **[Table 6]** have reported comparable findings for both zirconia and titanium. **Tete et al. 2009** found that the collagen fiber orientation around zirconia implants was parallel to the implant surface, which was similar to that of titanium[12].

Brakel et al. 2012 reported that zirconia had similar probing depth as titanium. The healing of soft tissue around the zirconia abutment and titanium abutment was reported by **Wellander et al. 2008** 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. Study was also found that zirconia had less mucosal Color change as compared to titanium, which was contraindicated by **Zembic et al. 2009**[16]

Brakel et al. 2011 found no significant difference in the soft tissue response around zirconia and titanium abutments. This finding was also similar to the study finding of **Kohal et al., 2001** wherein zirconia and titanium implants were inserted in the extraction sites of monkeys and both implants showed same peri-implant soft tissue dimensions[15].

Table 6 : Soft Tissue Response To Zirconia Implant

Author	Material	Parameters	Results
Brakel et al.,2012	Zirconia abutments Titanium abutments	Vascular density Inflammation grading scale	Vascular density Inflammation Scaling Zirconia 20.5±4.4 3.2±0.7, Titanium 20.7±3.2 3.1±0.7
Brakel et al., 2011	Grade 4 Ti screw implants and zirconia implants	Probing depth (PPD) Recession (REC), bleeding on probing (BOP)	Mean PPD 2Weeks 3 Weeks ZrO2 3(1.1) 1.7(0.7) Ti 2.9(0.8) 2.2 (0.8) Mean REC ZrO2 2.1(1.2) 2.7(0.6) Ti 1.9(1.2) 2.6(1) BOP ZrO2 50% 52.6% Ti 75% 47.4%
Tete et al., 2009	Machined titanium implant neck Machined zirconia implant neck	Collagen fiber orientationHistological examination at epithelium- connective tissue junction	Collagen Gingival Probing Fibers index depth Depth Zirconia 48% 0-1 2mm Titanium 58% 0-1 2mm
Zembic et al., 2009	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	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 at 2 and 5 months	PM-B(2Mont)PM-Aje(2mont) Zirconia3.08± 0.39 1.60± 0.31 Titanium 3.13± 0.331.80± 0.29 PM-(5mont) PM-Aje(5Mont) Zirconia 2.82± 0.39 1.60± 0.31 Titanium2.85± 0.37 1.83± 0.22

Table 7: Distinguishing Features In Between Zirconia Vs Titanium Dental Implants

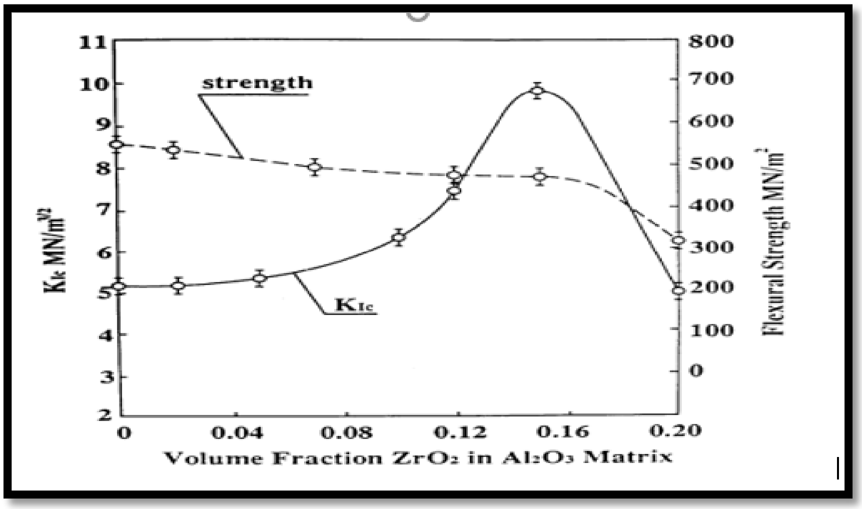
Titanium	**Zirconia**
As a metal, subject to corrosion and Galvanic reaction (cellular energy and meridian disturbance)	Zirconia is a ceramic, non-metal material without any metal properties. It is electrochemically inert causing no galvanizing or electro current disturbance effects at the inter and intra cellular level
Contains traces of metal like Ni, Ai, V, etc	Fully oxidized zirconium (Zr) is known as Zirconia (ZrO_2) which is not a metal and does not contain any metals, only ceramics
Not really an allergen, but triggers intolerances in some patients: • Increased prostaglandins E_2 • Increased interleukin 1 β • Increased TNF-α	No known allergies or intolerances. The most bio-inert and bio-compatible material on the USA and Europeans market
Higher surface free energy • Hydrophobic • Significant plaque may lead to inflammation • Acceptable soft tissue health	Lower surface free energy: • Hydrophilic • Reduced plaque accumulation may lead to less inflammation • Superior soft tissue health
Undesirable Aesthetics: • Thinning of gum tissue around implant • Grey shadow effect showing through gum • Does not resemble real tooth structure	Highly desirable aesthetic results: • Healthy, pink and beautiful tissue around implant • Resembles real tooth aesthetics
Observed bone erosion over long term and good bone osseointegration	Stimulates bone growth long term with ultimate osseointegration for both bone and gum, unlike Titanium

Biomaterials Associated With Zirconia

The term **Zirconia Toughened Ceramics** (ZTC) represent a wide class of materials and microstructures. Besides TZP and PSZ, another ceramic appears promising in biomedical application, Zirconia Toughened Alumina (ZTA). Very little was published on ZTA as a ceramic biomaterial although the results obtained in the development of a manufacturing process of ZTA ceramic ball heads by slip casting were recently reported[21].

ZTA structures can be formed by a fine and uniform dispersion of T-phase zirconia in the alumina matrix. The energy of the advancing crack induces a phase transformation of the dispersed zirconia grains, that due to their volume expansion in the T—M transition stresses the brittle alumina matrix, creating a microcrack network around the transformed particle. The fracture energy is dissipated in the phase transformation and in the increase of the crack surface into many microcracks, enhancing toughness[24].

ZTA structures can also be obtained by introducing metastable zirconia polycrystals agglomerates in the alumina matrix. Toughening is due to the cracks that will preferentially cross in their progress the zirconia particles with their Young's modulus lower than the one of the matrix. Stress induced phase transformation of the agglomerates will stop the advancing crack. In both cases the zirconia concentration in the alumina matrix has to be controlled so that the stresses due to phase transformation of zirconia do not compromise the strength of the ceramic[19] **(Graph 1)**



Graph 1: Fracture toughness and flexural strength of ZTA vs Zirconia content in aluminium matrix

Conclusion

The dental implant material search is still going on to find out perfect implant material. However, the above review highlights long-term promise that newer titanium-based alloys and zirconium based composite materials offer. Based on the peer-reviewed data osseointegration of zirconia implants may be similar to titanium implants. They also had well distributed and low stress distribution compared to titanium implants. Zirconia particles used in surface modifications of titanium implants might be having potential to improve bone healing and resistance for torque removal. The surface roughness of zirconia is comparable to titanium implants. Though fabrication of surface modifications is difficult for zirconia, CO_2 Lasers showed surface alterations to zirconia. Additional studies may aid improvements to improve surface roughness. Coated zirconia implants revealed higher removal torque compared to machined zirconia implants. For satisfying biochemical requirements, restoring of zirconia implants with high strength ceramics would prove beneficial. Though there are some short-term clinical reports provide satisfactory results, there should be controlled clinical trials having 5 year follow up or more should be done so as to evaluate properly, the clinical performance of zirconia implants so as to recommend them for regular clinical use.

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