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A Recent Updates on Zirconia Implants: A Literature Review

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Abstract

The most significant standard for dental implants' success is choice of an appropriate implant biomaterial. Titanium and titanium alloys are used extensively for fabrication of dental implants. Due to potential immunologic and potential esthetic compromises with titanium implants, new implant technologies are being advanced. Conversely, such new technologies should preserve the characteristics which offer titanium implants having their high rates of success. As a substitute to titanium implants, Zirconia implants were familiarized into dental implantology. Zirconia appears to be an appropriate implant material due to its low plaque affinity, tooth like color, biocompatibility and mechanical properties. This study aims at reviewing research and clinical articles undertaken regarding zirconia dental implants, comparing them with titanium dental implants, and offer information about zirconia dental implant mechanical strength and osseointegration. Zirconia dental implants possess the potential to be substitute dental implants to titanium dental implants, however yet they are not routinely used clinically.

Keywords: Biocompatibility; Mechanical properties; Osseointegration; Surface roughening; Titanium dental implant; Zirconia and implant surface coating; Zirconia and osseointegration; Zirconia dental implant

Introduction

The restoration of partially and completely edentulous patients having dental implants is a well-documented and scientifically accepted treatment modality [1].

Recently titanium alloys and titanium are frequently used in manufacturing implant and have turned out to be a gold standard for replacement of tooth in dental implantology. Such materials have achieved mainstream use due to their outstanding biocompatibility, well-documented useful results. When open to air, titanium instantly develops a steady oxide layer that forms the foundation of its biocompatibility. The oxide layer's properties are of great significance for the biological result of osseointegration of titanium implants [2-5].

Its dark grayish color is the main disadvantage of titanium that is noticeable through the peri-implant mucosa, hence impairing esthetic results in a thin mucosa biotype's presence. Recision of the gingiva or unfavorable soft tissue conditions can result in compromised esthetics. When the maxillary incisors are entailed this requires great concern. Moreover, reports propose that metals are capable of introducing autoimmunity and a nonspecific immunomodulation. Galvanic side effects after contact with saliva and fluoride are also described. However allergic reactions for titanium are quite infrequent, cellular sensitization is validated [5-7].

Due to such disadvantages new implant technologies producing ceramic implants are being developed. Conversely, ceramics are branded sensitive to tensile loading and shear, and surface flaws can result in earlier failure. Such realities suggest a high risk of fracture [8]. Recently, zirconia ceramics of high strength have become beautiful as new materials for dental implants. They are regarded to be sluggish in the body and display negligible ion release in comparison with metallic implants. Yitrium-stabilized tetragonal zirconia polycrystals seem to provide benefits over aluminum oxide for dental implants due to their higher flexural strength and their higher fracture resilience. They are used successfully for manufacturing ball heads for complete hip replacements in orthopedic surgery; still this is existing key application of this biomaterial [7-9]. Zirconia appears to be an appropriate dental implant material due to its mechanical properties, tooth like color and hence biocompatibility. Gingival recession and apical bone loss connected to implants frequently expose portions of the metal implant, disclosing a bluish discoloration of the superimposing gingiva. The utilization of zirconia implants evades such complication and agrees the request of several patients for metal-free implants. Also the material offers biocompatibility, fracture toughness and high strength. Bone resorption and the inflammatory response induced by ceramic particles are less compared to those induced by particles of titanium, recommending the bio-compatibility of ceramics [8-11].

Surface topography and material composition of a biomaterial play an essential role in osseointegration. Al-brektsson et al. state that the implant surface's quality is one key factor which influences healing of wound at the site of implantation and consequently affects osseointegration. Hence different physical and chemical surface modifications were developed for improving osseous healing. For improving surface properties, two key approaches can be used like application of bioactive coatings and optimization of micro-roughness. Zirconia dental implants' clinical use is restricted because surface modifications' fabrication is difficult, and smooth implant surfaces are not useful for osseointegration due to poor interaction with tissues [12].

Though zirconia can be utilized as an implant material by itself, particles of zirconia are used as a material of coating for titanium dental implants. A sandblasting procedure having round zirconia particles can be an alternate surface treatment for enhancing the osseointegration of titanium implants [13-17].

Several research articles were written regarding zirconia dental implants. Therefore this review's purpose is summarizing of research articles undertaken on zirconia dental implants, comparing them with

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titanium dental implants and offer information about osseointegration of zirconia dental implant [18-26].

Zirconia vs. Titanium

Zirconia as coating material on implants: Cranin et al. studied the osseointegration of vitallium implants with ceramic coating like alumina or zirconia [27]. Alumina coated implants and five zirconia vitallium implants showed failure after 32 weeks. Zirconia can be considered superior to alumina Nordlund et al. studied tissue integration of implant materials in monkeys:. Alumina with zirconia and magnesia, alumina with celicon carboide and unalloyed titanium implants. There was no difference observed of tissue reaction after 6-8 months. Frenchi et al. studied peri-implant tissues of zirconia coated and acid etched titanium implants [28]. All implants revealed new bone trabeculae, medullary spaces and close contact with bone at three weeks. They also evaluated per-implanted tissues for different surfaces at three months it was seen that implant surface morphology showed strong influence on rate and modality of per-implant osteogenesis. Bone deposition on the surface of titanium was seemingly favoured by rough surfaces such as zirconia-blasted implants. A research of same nature focused on the biological fixation for different zirconia sand-blasted titanium implant surfaces and a machined titanium surface and peri-implant osteogenesis. The highest bone ingrowth, Vickers hardness and BIC values were amounted in implants that were sand blasted with particles of zirconia that have higher values of surface roughness.

Titanium implant surfaces with a coating of zirconia, that could possibly have particular biological consequences. For uncoated titanium implants, the percentage of BIC was found to be 31.8-63.05%. The BIC percentage for titanium implants with zirconia coating at four weeks was 43.8-62.05%. The coating of zirconia was found to improve implant osseointegration [29]. An examination of peri-implant osseointegration by Bacchelli et al. revealed some interesting facts [30]. Machined titanium implants contained 34.5% of BIC, titanium implants contained 44.7% of BIC, alumina blasted titanium implants contained 53.4% of BIC and the amount of BIC in zirconia blasted titanium implants at two weeks was 35.5%. This remains to be the sole examination that revealed the fact that zirconia coating was not better than the other groups. This fact might be credited to the brief evaluation time of two weeks.

Zirconia as an implant: Akagawa et al. studied the initial interface of implant-bone with 1-stage zirconia screw implant and various conditions of occlusal loading after three months in beagle dogs [31]. There was no sign of superstructure in the non-loaded group. The loaded group contained metal superstructures. There was no considerable difference between the BIC of the two groups at three months. The values of BIC were 81.9% and 69.8% for the non-loaded and loaded groups respectively. The same investigators studied the function of osseointegration around 1-stage zirconia screw implant with different environments for loading support after functioning in monkeys for two years. In order to derive various concepts of support, three categories of superstructure were offered in each animal. The three categories were single freestanding implants, connected freestanding implants and a combination of tooth and implant. Every implant was immobile clinically for loading of 24 months. Healthy peri-implant mucosas was obtained in the groups of single freestanding, connected freestanding, and implant tooth support with very encouraging values for clinical parameters. The direct bone-implant interface was usually obtained in all studied implants of zirconia, histologically [32].

The BIC on three kinds of dental implants; alumina, titanium and zirconia was compared by Dubruille et al. These different types were positioned into the dog mandible [33]. The values of BIC at ten months were found to be 68%, 64.6%, and 54% for alumina, zirconia and titanium respectively. There was no statistically noticeable difference between the implants. The bone response to zirconia implants at four weeks was shown by Scarano et al. [34]. A considerable quantity of freshly formed bone was observed with zirconia surfaces. The value of BIC was 68.4%. These examinations resulted in understanding that zirconia implants are greatly osteoconductive and biocompatible.

The BIC of zirconia endodontic endosseous conis in apicectomy was assessed by Mosgau et al. [35]. The ratio of the circumference of total cone contact to the circumference of total cone tissue contact was 1.47 on zirconia surface 0.95 on the surface of titanium. This is an indication that bony healing is greater on zirconia surface than on the surface of titanium.

Kohal et al. assessed the hard and soft tissue conditions of sand blasted zirconia implants, comparing them with acid-etched and sand blasted titanium implants. The value of mean mineralized BIC obtained after five months of loading and nine months of healing were 72.9% and 67.4% for titanium and zirconia implants respectively [36].

A histological evaluation by Hoffmann et al. focused on the degree of early bone apposition around zirconia dental implants at two weeks and four weeks after insertion. The zirconia implants showed a little higher degree of bone deposition in comparison with titanium implants at the point of two weeks. However, bone apposition was higher in titanium in comparison with zirconia at four weeks [37].

Langhoff et al. studied the BIC of chemically altered titanium implants and SLA zirconia implants [22]. The zirconia implants showed bone contact which was 20% higher compared to that of titanium implants at two weeks. It was improved toward four weeks and reduced at eight weeks. Even though it is not significant statistically, a strong tendency was observed for the pharmacologically and chemically altered implants to present better values of BIC at eight weeks than the anodic plasma treated surface of zirconia implants. Every titanium implant contained similar amount of BIC at two weeks. It was found that only zirconia was better.

A research by Deprich et al. compared 24 screw type zirconia implants with acid etched surfaces 24 implants of pure titanium with acid etched surfaces [38]. The positive results of ultrastructural evidence of osseointegration of both implants were obtained. There was no considerable difference between the implants in terms of stiffness and strength at that time. The osteoblast behaviour on titanium surfaces and zirconia were compared in another examination [39]. Synthesis, rate of proliferation, attachment kinetics of bone associated proteins on each surface was examined and compared in detail. The examination of first day revealed that the zirconia surfaces' cell proliferation was akin to that of titanium surfaces. On the third day, the cell growth was found to be noticeable lower on the titanium surfaces than on the surfaces of zirconium. On the fifth day, cell proliferation went on to be greater on zirconia surfaces in comparison with the titanium surfaces. The last of the studies conducted by the group compared the osseous healing of zirconia implants with that of acid etched titanium implants having same macroscopic design. At first, fourth or twelfth week, BIC was a little better on titanium in comparison with zirconia surfaces. But there was no vast statistical difference between the groups. The results showed that the zirconia implants with altered surfaces caused an osseointegration which could be compared with the likes of titanium implants [6].

Surface analysis

Yang et al. examined zirconia with 3% Y2O3 and zirconia with 4% CeO2 coatings that were deposited on CoCrMo and titanium implants with the use of method of plasma spraying. Structural properties, adhesive properties, and morphological properties of plasma sprayed coatings were assessed. The mean surface roughness of zirconia with 4% CeO2 and zirconia with 3% Y2O3 was interrelated with the substrates and initial powder size. Hardness of substrates and the coatings showed no considerable difference. The adhesive strength of zirconia with 4% CeO2 coating t CoCrMo and titanium substrates was found to be greater than 68MPa and very much higher than that of zirconia with coating of 3% Y2O3 [1,40].

In yet another study, evaluation of machined Zirconia, SLA zirconia and sandblasted zirconia surfaces was done. There was an increase in surface roughness by airborne particle abrasion and acid etching. Cell proliferation showed statistically significant values greater at three days for surface treated zirconia compared to machined sample. But there were no observed differences among zirconia groups and SLA titanium for 6 and 12 days [41].

Gahlert et al. made another study on zirconia implants with sandblasted or machined surface and compared these to SLA titanium implants [5]. It was revealed by surface analyses that highest surface roughness was recorded for SLA titanium implant, followed by sandblasted zirconia and machined zirconia implant. In last study by Stubinger et al., effect of erbium-doped yttrium aluminum garnet, CO_2 and diode laser irradiation on the surface characteristics of polished zirconia implants were evaluated. SEM analysis revealed that the diode and ER-YAG lasers have not caused visible surface changes. But $C0_2$ Laser made distinct alterations to zirconia surface [42].

Removal torque testing

Study by Sennerby et al. observed the bone tissue responses to surface modified and machined zirconia implants [43]. To make the surface porous, zirconia implants were coated by two slurries containing zirconia powder and pore-former, which provided different surface structures. The non-coated implants were used as controls. Additionally, they used titanium implants. Coated zirconia and titanium implants revealed higher TRQ compared to machined implants. RTQ values of machined zirconia implants, SLA Titanium and sandblasted zirconia implants were evaluated by Gahlert et al. Machined zirconia implants exhibited statistically significant lesser values of RTQ than other implant types after eight and twelve weeks and SLA titanium implant showed higher RTQ values than sandblasted zirconia implant was 25.9 N/cm, while mean value for zirconia rough implants was 40.5 N/cm and mean value of RTQ for SLA titanium implant was 105.2 N/cm [1].

The effects of ceramic coating (hydroxyapatite and Zirconia) on bond strength between bone and implant was evaluated by Alzubaydi et al. along with cell compatibility of screw-shaped dental implants of titanium [44]. Biochemical testing was conducted at healing time points at 2, 6 and 18 weeks. RTQ value increase was observed in bone-implant interface against time and highest increment of bond strength was noted for implants which were coated with 50% hydroxyapatite and zirconia. The interface reaction between bone and coated implants was faster compared to uncoated ones.

By comparing biochemical properties of six types of implant surfaces, Ferguson et al. found that RTQ value for SLA Titanium was 1884 N/mm, SLA and calcium phosphate coated titanium was 1683 N/mm and SLA with anodic plasma chemical surface treated titanium was 919 N/mm, SLA with bisphosphonate coated titanium was 1835 N/mm, SLA Zirconia was 1005 N/mm and collagen-coated titanium was 1593 N/mm. At eight weeks, RTQ values for zirconia were lower significantly [45].

Strength

Minamizato et al. studied compressive strength of blade type zirconia dental implants having tunnels drilled by lasers and it was found that specimens having tunnels exhibited lower compressive strength compared to those without tunnels (237 kg/mm^2 and 371.5 kg/mm^2 respectively). They arrived at conclusion that zirconia blades showed adequate strength [46].

Kohal et al. evaluated fracture strength of the titanium implants with metal / ceramic crowns, zirconia implants with Empress I Crowns and implants with Procera Al_2O_3 based crowns before and after their exposure to artificial mouth. In non-loaded group, titanium fracture strength was 531.4 N, for zirconia Empress I, it was 512.8 and for zirconia Procera, it was 575.5 N [47].

After chewing load of 1.2 million cycles, titanium's fracture strength was 668.6 N, for zirconia Empress it was 410.7 N, and for Zirconia Pocera, it was 555.5 N. The fracture values for Procera crowns and metal ceramic after artificial loading were considerably higher than for loaded Empress I crowns. The zirconia implants which were restored with Procera crowns may fulfill biochemical requirements of anterior teeth.

Silva et al. examined effects of full crown preparations on reliability of 1-piece zirconia implants [48]. They observed that zirconia implants' fracture strength without preparation was 1023.3 N and with full crown preparation it was 1111.7 N. But another study concluded that the preparation of implant heads showed considerably negative influence on fracture strength of implant. Fracture strength of 1-piece zirconia implants after exposure to artificial mouth with clinical service of five years was estimated. Zirconia implant fracture was observed at 725-850 N without implant head preparation. They concluded that mean fracture strength for zirconia implants fell within clinical acceptance limits [15].

Stress analysis

A study by Kohal et al. evaluated stress distribution patterns in zirconia implants [49]. and these were well distributed and these were compared to identical distribution with titanium implants. The patterns might be characterized as nondestructive or favorable. For both models stress values were identical for all regions.

Clinical studies

Zirconia implants were investigated in three clinical studies. Study by Blaschke et al. noted that zirconia dental implants were feasible alternatives to titanium implants [50]. Along with superb cosmetic results, zirconia implants permit a degree of osseointegration and soft tissue response superior to titanium implants. Olivia et al. report the first clinical evaluation on hundred zirconia implants (CeraRoot, Spain) with two different surface roughness in humans after one year follow-up. Two of these failed after fifteen days. These were placed where sinus elevation was needed. Success rates were reported to be 98%. Given the requirement of sinus elevation, future researchers may exclude patients having residual bone less than 5 mm. Picker et al. put a zirconia implant at maxillary first premolar region and evaluated clinical outcome of the implant. After a two year follow up, stable implant and unaltered pen-implant marginal bone levels were noted. There was no bleeding on probing [51,52].

Case reports

Kohal et al. presented a first clinical case report of zirconia dental implant [53]. A custom built two-piece zirconia implant replaced a left upper central incisor with the zirconia abutment and zirconia single crown. Additionally, Oliva et al. reported a first clinical case of ovoid zirconia implant. A specially designed, anatomically oriented ovoid zirconia implant was used to replace missing premolar was discussed [54].

Recent Developments in Titanium Based Implant Biomaterials

New developments in R&D in titanium-based biomaterials have the aim of developing alloys with non-allergic and nontoxic elements having excellent mechanical characteristics such as high strength and low modulus, and good workability [54]. These developments are attempting to replace aluminum and vanadium with non-toxic components like Fe, Nb, Ta, Mo, Pd and Zr. These materials exhibit lower modulus of elasticity which is near the value of bone (17-28 GPa) and are also ® alloys. The lower value of modulus of elasticity is beneficial as it produces a more favorable distribution of stress in bone implant interface [55-57]. Also, these alloys can attain higher strength and toughness. Recently, a new alloy has been developed for manufacture of narrow diameter implants (by name Roxolide, Straumann, Basel, Switzerland) for use in dentistry. The new alloy is based on binary formulation of titanium (83-87%) and Zirconium (13-17%). This is claimed that the alloy has better mechanical properties compared to CpTi and Ti-6Al-4V, having a tensile strength of 953 MPa and 40% more fatigue strength. Adding Zirconia to the Titanium results in better osseo-integration and the alloy made of Zirconium and Titanium exhibits more bio-compatibility than pure titanium [38].

Another titanium alloy in the application of surgical implant material is Ti12.5Zr2.5Nb2.5Ta or TZNT which is very promising. This alloy has the unique advantage of having closer modulus of elasticity to human bones compared to conventional titanium alloys. It also has approximately same equivalent admission strain (at 0.65%) compared to human bones (at 0.67%). Adding the elements like, Zr, Ta and Nb to alloy have detected no toxicity or adverse tissue reactions. They also show better resistance against corrosion [58].

Recent Developments in Zirconia Based Implant Biomaterials

Presently, considerable research is going on with the aim to improve reliability of ceramics generally and specifically about zirconium-based biomaterials in mainly biomedical and dental applications. There are several developments focusing on application of zirconia and alumina ceramic composites which consist of ZTA or ATZ. Generally, such advanced composites gain benefits due to transformation toughening characteristics of Zirconium and also are less vulnerable to degradation in biological fluids at low temperatures [4].

Recently, ceramic blocks called as TZP-A was produced by adding small quantity of alumina to 3Y-TZP. Alumina traces improved stability and durability under humid environments and high temperatures. But this was achieved at the compromise of reduction in translucency of ceramic blocks and hence it is considered aesthetic disadvantage [38].

Minimizing LTD in 3Y-TZP systems is attempted by adding small quantities of silica, using yttria-coating instead of co-precipitated powder, reducing grain size and increasing stabilizer content and formation of composites with Aluminum Oxide (Al_2O_3). The composite material processed with tertragonal zirconia polycrystals (ZrO2-TZP) and Alumina at 20% (Al_2O_3) is claimed to show excellent mechanical and tribiological characteristics. Adding alumina to Zirconium reduces aging or in the least, diminishes its kinetics as it alters from grain boundary chemistry and limits tetragonal grain growth during process of sintering, resulting in more stable structure. Another enhancement in Zirconia is Zirconium based bulk metallic glass; for example, Zr61Ti2Cu25Al12ZT1, which exhibits good combination of high fracture toughness, strength and lower Young's Modulus. Metallic glasses or amorphous alloys have almost uniform microstructure compared to conventional crystalline materials having no defects such as grain boundary or dislocation. Also, short range of atomic arrangement takes place in case of amorphous solids compared to long range order of the crystalline solids. This provides many beneficial properties like high yield strength, elastic strain (about 2%), and high corrosion resistance. These properties have made use of Zr-based bulk metallic glasses preferable for implantology [38].

There are also advancements made with Zirconia in terms of enhanced surface topography and the modifications providing improved osseointegration.

Several studies and experiments are conducted to achieve surface modified zirconia-like sand blasted, sand-blasted light grit and plasma anodized, acid etched and ceramic coated zirconia. The tests have shown stronger bone response to sand blasted and acid etched Zirconia implant surface [4,18]. The coated or surface modified Zirconia implants also showed higher value of removal torque compared to machined implants of zirconia. With various surface enhancement methods to roughen zirconia surface, it is found that the surface roughness is comparable to that of titanium implants. Even though it is hard to achieve surface modification to zirconia, with the help of procedures like CO_2 lasers, it is possible to produce distinctive surface changes to zirconia. Ceria stabilized Zirconia or Alumina nano-composites for dental applications have shown to have high flexural strength, reliability and high resistance to low temperature degradation. More research is required for evaluation of long-term in vivo performance of the composites in oral environment. It is also well-documented that a good favorable implant surface and the tissue interface are necessary for the successful dental implant outcome. Improving of implant topography at nanoscale is a key element in eliminating rejection and enhancing osseointegration [58].

Conclusion

The search for "perfect" dental implant material is on. 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. Also, 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. Surface modified or 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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