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Zirconia dental implants design: where are we now, and where are we heading?
Root analogue Zirconia Implants: A novel approach

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Abstract:

The purpose of this systematic review was to assess the published data concerning zirconia dental implants from various aspects. Titles and abstracts were screened and articles were selected for full-text reading. Articles were divided into three groups: 1) studies evaluating the surface modification of zirconia implants, 2) studies on root analogue zirconia implants, 3) studies on a one-piece or two-piece zirconia implant.

The literature searches for articles written in the English language in PubMed Library database from 2004 till December 2018. The following search terms were utilized for data search: "zirconia implants" NOT "abutment" or "prosthesis", "zirconia implants" and "zirconia implant design" AND "root analogue zirconia implant", "one-piece, two-piece zirconia implants".

The number of potentially relevant articles selected were42. All the human in vivo clinical, in vitro, animals' studies were included and discussed under the following subheadings: Surface modification, root analogue zirconia implants, Physical and mechanical properties, the biocompatibility of one-piece and two-piece zirconia implant and Peri-implant tissue compatibility.

There is sufficient significant data on various parameters to conclude that zirconia implants with different sizes, shapes and designs are a promising alternative to titanium considering mechanical and biological properties. Improvement in the reliability of zirconia implants, permitting for unique designs, connections and reconstructions. Consequently, the clinical performance of zirconia implants is recommended for routine clinical use.

Keywords: Zirconia, dental implants, Tissue compatibility

1- Introduction:

Implantology has been applied in dental practice for over 35 years as a means of rehabilitating missing single or multiple teeth [1, 2, 3]. For the past thirty years, pure Titanium has been used in the manufacture of dental implants as the best substrate and showed very good prognosis [4]. The success of Titanium implants is attributed to the convenience of their physical and mechanical characteristics as well as good biocompatibility; which made them sufficiently stable with a long lifespan [5]. Perhaps the main disadvantage of Titanium is its unaesthetic nature, as it's grey color can be sometimes visible in cases where bone resorption leads to soft tissue recession and in patients with thin soft tissue biotype [1, 6]. With the continuous increase in aesthetic interest, Titanium's unfavorable grey color is potentially problematic, especially when the anterior teeth are involved. The grey color may become visible in cases where bone resorption and gingival recession around the implant occur [1, 6, 7.[

So far, Titanium has been the first-line material for surgical use and the manufacture of dental implants [1]. In addition to its use in tooth replacement in implantology, Titanium is also the material of choice for supporting fixed single tooth reconstructions as well as removable and fixed prosthesis [9]. However, Zirconia has been recently introduced as a potential alternative [1, 10, 15]. Zirconia has very good mechanical properties and is suspected to allow less plaque accumulation [10]. Zirconia was proved to provide large bone-implant contact with biocompatibility similar to that of Titanium [1, 4, 12, 16]. Due to all these favorable Zirconia properties, it is currently used in ceramic abutments and frameworks in implants [16-18]. Carcinogenic and mutagenic effects have also been evaluated in vitro and showed negative results [4, 17]. Simulated loading was conducted on Zirconia and it showed promising load-bearing capabilities in the long term [3]. Pure Zirconia is found in two forms; crystalline and amorphous. Crystalline zirconia, which is white in color and soft and ductile. The form used in dentistry is amorphous zirconia, which is found in nature as a bluish-black powder. The amorphous powder is refined and then crystallized at high temperature resulting in optically translucent crystals. Afterwards, homogenous implants with accurate measurements are formed through filling the purified powder into malleable dies, upon which high pressure (2000-4000) and temperature are applied.

Zirconia implants exhibit three crystalline phases; the first of which is the monoclinic (m) phase which is detected at room temperatures and remains stable until a very high temperature (11700C) is reached. At this point, the monoclinic phase is transformed into tetragonal (t) leading to volume reduction by 5%. Further, the rise in temperature to 23700C causes the formation of the cubic (c) form. The cooling process from 1170 C to 1070 C leads to reformation of the monoclinic phase from the tetragonal phase with an increase of 3-4% in volume [8]. Unfortunately, Zirconia is reported to degrade when exposed to low temperatures, thus compromising its longevity. The problem is that the material's exposure to water or water vapor causes tetragonal to monoclinic phase transformation. This, in turn, leads to slow roughness formation and continuous degradation of the material [17, 19]. While macro design denotes thread shape, prosthetic connection and collar design; the micro design is concerned with the implant material and surface morphology and treatment [20]. The design of the implant employs several shapes such as smooth and threaded implants. The critical requirement for all shapes is the implant ability to endure masticatory forces and transfer them to the interfacial tissues [21]. Implants are manufactured in one or two pieces, but the former type is more common because it has superior mechanical properties and is less difficult to fabricate. There is considerable demand on the two-piece implants in dental implantology market, although their mechanical properties and inter-abutment connections are not sufficiently investigated [22]. The first tooth analogue dates back to 1969. It was made of polymethacrylate and was encapsulated by soft tissue as osseointegration was not yet applied. Titanium was used in an experimental model by Lundgren and colleagues with immediate implant placement with bony integration in 88% [23]. Customized zirconia root analogues are an attractive alternative to Titanium because it has more favorable aesthetic properties, better stress distribution and better peri-implant tissue compatibility [24 .[

The fundamental objective of this study is to evaluate the development of zirconia implant design throughout the period from 2004 to December 2018.

2- Surface modification of zirconia implants

Zirconia –just like Titanium- was tested on animals and showed that intraosseous implant surface roughness enhances bone apposition. Surface modification of zirconia implants provides them with osseointegration capacity similar to that of titanium implants [7]. In addition to using zirconia in the manufacture of implants themselves, it is also used for coating titanium implants and sandblasting them [25]. Surface modification was found to improve bone apposition and bone in-growth. The process also increases surface area and promotes water penetration into the bulk and/or modifies the tetragonal phase resistance to humidity [26]. Surface properties largely affect bone-implant integration of the Zirconium Dioxide implants despite evidence of the osseointegration of the implant. Surface roughness also contributes to the implant cell attachment [27]. Surface roughness is important in all implants to allow good contact area with the surrounding bone tissue. Coronal circumference topography of the implant affects the marginal bone level [28 .[

The shear bond strength of the zirconia implants can be significantly enhanced through surface topography and mechanical treatment as well as chemical silanization of silicated zirconia and application of zirconia primer on zirconia [15]. Previous studies have shown that the application of microgrooves to the implant surface can direct cellular morphology and cell migration, improve cell adhesion and also improve cell differentiation and mineralized matrix deposition. Femtosecond laser ablation has recently experimented in micro structuring cylindrical zirconia implants. The procedure was found successful in terms of increased roughness and oxygen presence at the treated surface with a decrease in the m-phase and surface contaminants such as carbon and aluminum [28]. The difficulty of the roughening process lies in the material's resistance to chemical or physical treatments. The suggested techniques include sand-blasting and acid etching, chemical and pharmacological surface modification, bioactive coatings (with calcium phosphate, bisphosphonate or collagen type I with chondroitin sulphate), anodization and machining, application of nanotechnology and addition of micro- and macro-retentions [8, 28]. Surface modification techniques may cause mechanical damage, which may be overcome through laser treatment of these zirconia implants [30]. There are many relations between surface modification and:

a- Removal torque

Surface modification of zirconia implants increased surface roughness and resistance to removal torque, achieving a good level of stability [28]. In a recent study, removal torques were calculated eight and twelve weeks after implantation of machined zirconia, sandblasted ZrO2 and Ti-SLA implants. The removal torques (RTQ) at eight weeks of the ZrO2 was significantly higher than that of machined zirconia and significantly lower than that of Ti-SLA implants.

The mean RTQs ranged between 75.7 and 132.8 N/cm for SLA implants, whereas the corresponding values ranged between 23.3 and 29.1 N/cm for machined ZrO2 implants and 34.8 and 46.9 N/cm for rough-surfaced ZrO2 implants. The mean RTQs for machined ZrO2, ZrO2 rough and Ti SLA implants were 25.9, 40.5 and 105.2 N/ cm; respectively. Also, the mean RTQ value of ZrO2 rough implants was always higher than that of the machined ZrO2 implants. Surfaces of both blasted ZrO2 and SLA titanium implants showed similar micro-roughness in the scanning electron microscope pictures, but the former still had a flatter profile with lower porosity level. With a mean roughness (Sa) of 1.15 mm, the titanium SLA surface is double as rough as the sandblasted ZrO2 surface (Sa of 0.56 mm). In comparison with the machined ZrO2 surface, the lowest mean roughness was detected with a Sa of 0.56 mm [7, 27.[

Furthermore, zirconia implants were compared with Ti-SLA implants in a non-inferiority test and proved to be non-inferior to them, accepting the difference in RTQ between the Zirconia and Ti of 41, 55 and 60 Ncm, at 4, 8 and 12 weeks, respectively. For instance, there was no statistically significant increase in the mean RTQ values in the time between four and eight weeks, while the values were significantly increased from eight to twelve weeks ($P = 0.0309$ and $P = 0.0115$, respectively) [1]. However, in-vitro tests compared the effectiveness of experimental zirconia implants having differently treated surfaces (sandblasted and etched versus sandblasted only) with implants of identical dimensions having a reference titanium surface. The initial findings after four weeks of the placement indicated significantly better surface performance by the reference titanium surface (244.5 Ncm) than both types of zirconia surface. It was also found –at the same time point- that combined sandblasting and etching gave significantly higher performance than sandblasting alone (111.8 and 55..9 Ncm, respectively). However, there was a significant change in the testing results after 13 weeks of the placement of the implant. The sandblasted zirconia managed to compensate for the performance difference from the etched surface in the period from week four to week 13 (99.4 versus 100.3 Ncm). Nevertheless, the RTQs of the reference titanium surface was still higher with a statistically significant difference (221.9 Ncm). The values also indicate little change in the RTQs of the sandblasted and etched zirconia and the reference titanium surfaces in the period from four to 13 weeks .

A significant difference between zirconia and titanium surfaces has also been found in the results of mechanical testing. The mean removal torque values have exhibited a clear superiority of titanium surfaces over both tested zirconia implants at both intervals. The same study demonstrated a statistically significant difference between the RTQs of titanium and zirconia surfaces at four and eight weeks of the implantation in favor of titanium [18]. Another experimental study was performed on 25 rabbit tibiae to test the removal torques of powder injection molded (PIM) zirconia implants. The rabbits were divided into four groups receiving dimensionally identical hex implants of PIM zirconia implants, roughened PIM zirconia implants, (Ti,Zr)O2-coated PIM zirconia implants or (Ti,Zr)O2-coated roughened PIM zirconia implants. The mean RTQs for the four groups were 0.56 Ncm, 44.27 Ncm and 64.35 Ncm; respectively. This indicates better mechanical properties in roughened-surface implants attributable to mechanical interlocking [25.[

An experiment was conducted on beagles to test the removal torques of injection-moulded zirconia implants. The implants were divided into three groups: titanium implant with RBM surface (Group RT), injection-moulded zirconia implant (Group Zr) and injection moulded zirconia implant with a sandblasted surface (Group ZrS). The mean removal torque values (±SD) were 57.9 (±17.3) Ncm (Group RT), 72.0 (±25.6) Ncm (Group Zr), and 58.3 (±16.5) Ncm (Group ZrS), respectively. The RTQ values of the Zr group were a little higher than the other two groups, but the three groups showed no significant differences; indicating that the injection-moulded zirconia implants have comparable properties to RBM-surfaced titanium implants. The study also demonstrated that sandblasting the injection-moulded zirconia hardly affected its RTQ values. After 12 weeks of the implantation process, the RTQ values of all groups showed no statistically significant differences despite the differences in surface roughness. This demonstrates a very weak relationship between surface roughness and the removal torque. This concluded similar osseointegration with injection moulded and RBM titanium implants after 12 weeks indicates similar RTQ. This means that, in terms of removal torque, RBM titanium implants can be replaced with injection-moulded zirconia implants [31.[

b- Peri- implant area

The mucosal barrier between the implant and the soft tissue (also called the soft-tissue-to-implant interface) is of a pivotal role in maintaining the health of the peri-implant region. The quality of the interface is strongly related to the surface properties of the inserted implant [17]. One study reported that peri-implant osteogenesis was better in (Ti, Zr) O2-coated powder injection moulding compared with uncoated regardless of implant surface roughness [25]. Another study indicated that the low-modulus coating of a dental implant significantly reduces the maximum load on the peri-implant bone without affecting the average loads, thus promoting a better biomechanical property. The study suggests that a thick, low modulus coating could reduce the maximum compressive and tensile stresses in the peri-implant bone by up to 50%. The average stress is also affected but to a smaller extent (of about 15%) [32]. This loss in stress on the peri-implant bone tissue is unfavorable because it compromises the stability of the hard and soft tissues in the long term [33]. A histomorphometry study was conducted on dogs and revealed that the peri-implant soft tissue of the no submerged uncoated zirconia implants consisted of 65% barrier epithelium and 35% connective tissue on average. The submerged uncoated zirconia implant, however, showed equal percentages of barrier epithelium and connective tissue [34.[

c- Implant stability and marginal bone level

Modifying the zirconia implant surface was found to influence the response of the bone tissue [1]. Cortical bone density and thickness are critical effectors on implant stability. To promote the healing process, and thus, achieve successful implantation, primary implant stability and prevented micromotion are of undeniable importance. These properties depend on the surgical technique applied as well as the bone density at the implant placement site. Another important factor is the bone-implant contact area, which relies on the implant macro and micro design [28]. A documented case report [35] investigated the application of screw-type implants with multiple external patterns. Time of insertion, initial stability and insertion torque were all better than those observed in single-thread screw-type implants. The report revealed that tapered screw implants can result in better stability in soft bone compared with non-tapered screw implants if proper surface roughening and multiple thread patterns were applied and enhanced technological procedures were used [35 .[

In a study that sought to evaluate the possibility of applying a new shape with hollow and porous configuration. This structure is reported to allow better bone growth into the lower part of the implant, leading to fastening the implant into the alveolar bone. The increased contact area and consequent bone ingrowth are mainly attributable to the interior cavity and the radial tunnels. Eventually, an interlinked network is formed due to prolonged bone growth on the inner and outer sides of the implant. The network helps in anchoring the implant into the alveolar bone, enhancing its rigidity. The rigidity resulted from the adsorption of the glass coatings into zirconia and the growth of bone on the glass coatings inside and outside the zirconia implant. Although it may take more time, bone growth still occurs in materials of less compatibility and materials uncoated with bioactive substrates, but it might take more time. Therefore, the hollow and porous structure did have a role in providing greater implant rigidity [41 .[

d- Histologic and histomorphometrically findings

Osseointegration is a term stems from Bra˚nemark's works. It is now described as a "direct structural and functional connection between ordered living bone and the surface of a load-carrying implant." Osseointegration is strongly dependent on the implant surface as it is related to the implant-surface contact area. The implant surface properties determine the rate of this bone integration and influence the biomechanics of the bone/implant connection [32]. Although some suggested that a rough surface texture on implants undergoing immediate loading would be useful, a deeper understanding is required regarding the effects of frictional coefficients of BII from various surface textures of immediately loaded implants on micromotion at the bone-implant interface (BII) and stress distribution in the bone .

In a study conducted in 2010, the performance of experimental zirconia implants with two different surfaces was compared with a reference sandblasted/acid-etched titanium surface on implants of identical geometry. Bone integration was evaluated through measuring the BIC values after four weeks and 13 weeks of the implantation process and the results were compared. At four weeks, both sandblasted zirconia and sandblasted/etched zirconia gave BIC and BVD (bone density) values similar to that of the control titanium implants. However, at 13 weeks, neither of the zirconia surfaces could achieve the BIC values of the sandblasted/etched titanium. In-vivo, the same study reported that the early peri-implant histologic behavior with zirconia implants was a little different from the one with the tested titanium surface. Close examination of the regeneration process revealed that the bone formation patterns on the surface of the osteoconductive bone were better on sandblasted/etched titanium, forming thin extensive layers of newly generated bone; unlike the few spot-like contacts intervening non-mineralized tissue layer observed with zirconia [18 .[

Another study conducted in 2012 compared the peri-implant bone density and the BIC values of acid-etched ZrO_2 implants and SLA titanium implants at four, eight and twelve months after implantation. The results indicated no statistically significant difference in the BVD and the BIC values between the two implant types. Therefore, testing zirconia on animals can prove that roughened implant surface can enhance bone apposition and osseointegration just like titanium [7]. BIC is also improved when the zirconia surface is modified [7, 15]. Submerged zirconia implants exhibited higher peri-implant BVD than titanium in animals, but clinical studies are still needed to prove the same results in humans [15]. Another experimental study was performed on 25 rabbit tibiae to test the osseointegration of smooth and roughened powder injection moulded (PIM) zirconia implants. The rabbits were divided into four groups receiving dimensionally identical hex implants of PIM zirconia implants, roughened PIM zirconia implants, (Ti,Zr)O2-coated PIM zirconia implants or (Ti,Zr)O2-coated roughened PIM zirconia implants. All zirconia implants showed peri-implant bone regeneration. The average BICs for Groups 1, 2, 3 and 4 were 59.59%, 61.52%, 72.88% and 69.86%, respectively. Although BIC values are the commonly measured indicator in vivo, the quality of the provided structural support surpasses the quantity of the BIC value [25 .[

In a study about histologic and histomorphometry behavior of micro grooved zirconia dental Implants with immediate loading, the following conclusions were drawn:

-1Sandblasted zirconia implants with micro grooved intraosseous portion demonstrated higher BIC and BVD values than both sandblasted/acid-etched titanium and sandblasted zirconia dental implants .

-2CBL small decrease was observed in all implant types, and crestal bone remodeling was detected despite the neck microgrooves.

-3Higher BIC and BVD values were found around splinted implants with immediate loading after three months of implant placement .

-4The mean ST thickness was 3mm in all tested implants, indicating the establishment of the biologic width [30].One can conclude that the peri-implant crestal bone levels depend on implant design, location and coronal supported restorations in all the studies that compare zirconia and titanium implants [13 .[

3- One-Piece and Two-Piece Zirconia Implants

One-piece and two-piece zirconia implants are currently available in the market [9, 11]. However, most fabricated zirconia implants are of the one-piece design [3, 11, 17, 37, 38]. Since the main motive for using zirconia implants is their favorable aesthetic character, good aesthetic outcomes can only be achieved through optimizing the angular and apicocoronally positions [4]. Although one-piece implants require very little surgical invasion, provide excellent soft-tissue protection, and can be restored immediately with interim crowns; their anatomic positioning must be accurate, which is not easy in the front aesthetic region. Therefore, two-piece implants are sometimes needed [11]. Little data is available on the two-piece Y-TZP implants. One in-vitro study tested the restoration of these implants with two different all-ceramic crowns. However, the implants could not endure the static and cyclic stress, and therefore could not be implemented clinically [4]. In practice, sometimes the implants are not positioned correctly, and their angulation requires adjustment to achieve the desired prosthetic outcome. Another factor supporting the use of two-piece implants is the immediate exposure of one-piece implants to chewing forces and tongue pressure after insertion. Only little is available on the two-piece implants provided by a small number of manufacturers. This is probably attributable to the experimental results indicating their lower fracture strength and higher fracture rates than one-piece zirconia and two-piece titanium implants [33.[

An in-vitro pilot study examined the stability of prototype two-piece zirconia and titanium implants after artificial ageing. In this laboratory investigation, the rhe implants were divided into three treatment groups, each comprising 16 specimens. In group 1, two-piece zirconia implants were restored with zirconia crowns (zirconia copings veneered with Triceram®; Esprident, Ispringen, Germany), and in group 2 zirconia implants received Empress® 2 single crowns (Ivoclar Vivadent AG, Schaan, Liechtenstein). The implants and their abutments were identical in the two zirconia groups. In group 3, similar titanium implants were reconstructed with porcelain-fused-to-metal crowns. Upon experimentation in an artificial mouth, seven implants failed, one of which was in group 1 (veneer fracture), none in group 2 and six in group 3 (implant abutment screw fractures.(

The artificial load applied to the implants was 1.2 million cycles. The resulting fracture strength values ranged between 45 and 377 N (mean: 275.7 N) in group 1, between 240 and 314 N (mean: 280.7 N) in group 2 and between 45 and 582 N (mean: 165.7 N) in the titanium-implant group. Without artificial loading, the fracture strength values were significantly higher; between 270 and 393 N (mean: 325.1 N) in group 1, between 235 and 321 N (mean: 281.8 N) in group 2 and tween 474 and 765 N (mean: 595.2 N) in group 3. The fracture patterns differed between zirconia and titanium implants. While the former group demonstrated head fracture, the latter exhibited bending/fracture of the abutment screw [39]. One-piece zirconia implants sometimes show early fractures, especially when inserted in the posterior region. This factor is crucial for the approval of its application in clinical practice [8]. The highest stress and torque are concentrated on the screwed connection, so it is a point of weakness in the implant system. Considering the brittle nature of Zirconia, it is hard to achieve screwed connections, due to the increase of screw loosening or misshaping. With single-part implant systems, preventing micromotion is essential. Noting the possible issues occurring in the mechanics of zirconia implant parts, several manufacturing companies prefer to provide single-part implants, as their durability has been established. One-piece implants must be correctly positioned, and then the trans-gingival healing period is necessary without implant loading. If the abutment is severely damaged, the implant cannot be restored and its removal is inevitable. Abutments usually require intraoral preparation. Water cooling is necessary throughout the process to overcome heat generation and decreased fracture strength. The abutments, then, need to be well repolished to smoothen the surface, but many dentists neglect this step. The application of one-piece and two-piece zirconia implants in anterior teeth was tested. The implants were divided into two groups of bonded two-piece zirconia (ZZB), four groups of one-piece zirconia (Z) and two groups of two-piece titanium (TTS, reference). Identical prostheses of monolithic zirconia crowns were used in all groups. Both one-piece zirconia and two-piece titanium groups were successful, but the two-piece implant system could not survive the TCML and fractures occurred in the implants or abutments. Failures ranged from 1x in one group and 5x in two groups [6]. Immediate loading on one-piece zirconia implants was tested throughout five years. Thirty-two implants were divided into two equal groups; the first group were immediately implanted and the second was implanted after healing in a total of seventeen patients. Clinical and radiographic outcomes were evaluated at various time points. One immediate implant failed after 3 months, and one patient with one implant withdrew from the experiment after T1 after one year". Therefore, the cumulative survival rates were 96.9% at T1" and 96.8% at T2" after 5 years" (4.3 to 6 years). Values of mean Marginal Bone Loss showed no significant differences between immediate and delayed implants at both time points. None of the baseline parameters (such as sex, implantation site, smoking) affected the MBL at any time interval. In terms of the clinical parameters of "Probing Depth (PD), Modified bleeding index (mBI), Modified Plaque index (mPL) and Gingival Recession (REC)"; implants behave like or better than natural teeth [5]. Therefore, one-piece zirconia must be left without loading to ensure good healing and desirable prognosis [8]. A pioneer prospective cohort study examined the success of one-piece zirconia implants in replacing a single tooth. Investigating clinical as well as radiologic implantation results, the study provided one-year follow-up data on survival rates, bone remodelling/loss and soft tissue parameters. In detail, 66 ceramic ZiUnite™ implants were placed in 65 patients. Most of the implants were inserted into the lower jaw (48), and the remaining were inserted into the upper jaw (18). Forty-five of the placed implants were wide-platform implants with a diameter of 5 mm and 21 were regular platform implants with a diameter of 4.3 mm. Only five implants were placed immediately after extraction. 19 implants were placed in healed sites using the flapless (punch) approach and 42 implants were inserted through raising the mucoperiosteal flaps.A total of three implants failed before prosthesis, but there were no further failures at the 6-month or 1-year evaluation times. This gave a one-year cumulative survival rate of 95.4%. Marginal bone remodelling was examined radiographically and bone loss was calculated for all remaining implants. The average bone loss was 1.13 mm. Until the time of prosthesis, radiographs showed that bone gain was observed in 8 implants (14% of the total implants), while bone loss resulted in the remaining implants (with 16 implants showing more than 2 mm loss and 7 implants showing more than 3 mm loss). However, the average of total bone loss throughout the one year of the study reached 1.31 mm. Only seven implants gained bone, while 19 implants exhibited more than 2 mm bone loss and eight implants demonstrated more than 3 mm bone loss. Radiographic analysis indicated more bone loss in the one-year evaluation, with vertical bone defects of narrow or wide nature [37.[

Nevins et al compared the clinical and histological outcomes of 2-piece zirconia implants and titanium implants. The investigation included the implantation of four titanium and two zirconia implants in a healthy woman. One of the zirconia implants was removed six months later for making a biopsy. The study indicated that osseointegration was detected in all implants. Periodontal health was good, and radiographs showed great vertical bone length. BIC values indicated good osseointegration, denoting that zirconia implants allow for good soft- and hard-tissue healing. Another clinical study conducted in 2013 investigated the use of two-piece zirconia in front teeth replacements. At six-months follow up, these maxillary implants were successful and the patient satisfaction was achieved [35]. A histomorphometry study compared the soft tissue healing in dogs receiving one-piece zirconia implants and titanium and PEEK implants of identical geometry. Each of the six mongrel dogs received four one-piece implants on each side of the jaw: an uncoated zirconia implant, a zirconia implant coated with a calcium liberating titanium oxide and an experimental implant made of synthetic material. The implants were placed in submerged and no submerged healing sites. Histological investigations were conducted four months after fixation to evaluate the implant mucosa marginal side, the apical extension of the barrier epithelium, and the margin level of bone-to-implant contact. Tissue inflammation was also evaluated in the crystal region. Histological composition next to the BIC showed natural soft tissue morphology of barrier epithelium and connective tissue formation. The length of the barrier was similar in both material types and both healing types. Inflammatory signs were clearer in the no submerged implants, with little inflammation in the uncoated submerged type [69]. A preclinical histometric study investigated the bone response to functionally loaded, two-piece zirconia implants. The implants were given an unloaded initial healing period and were then functionally loaded for four or sixteen weeks. The results indicated implant durability similar to that of a well-documented titanium implant with a similar surface property. Neither the cement-retained test nor the screw-retained control groups showed any biological or technical complications [38]. Successful osseointegration requires primary stability and absence of micromotion. Two-piece implants are advantageous in cases where the primary stability is not realized, as they minimize force transfer to the bone-implant interface. Primary stability and the elimination of micromovements are the main factors required for successful osseointegration. Two-piece implants can minimize the forces transmitted to the bone-implant interface and can be used when accurate primary stability is not achieved. The information on 2-piece zirconia implants is limited to 1 biomechanical, 1 animal, and 2 clinical studies [23]. A biomechanical study applied artificial ageing to test the fracture strength of restored prototype 2-piece zirconia compared with restored titanium implants. The results indicated high fracture rates in both types (head fractures in zirconia and the abutment screw level fractures in titanium implants). This concludes that the two types have little use in clinical practice [39]. In a numeric analysis comparing the mechanical properties of titanium and zirconia, single-piece zirconia and titanium dental implants with identical dimensions were subjected to nine different loading types to resemble incisive mastication. The two types showed similar numeric measurements and stimulation patterns, indicating potential mechanical equivalence of the two materials. 3D Finite Element Method “FEM” was applied and the stress and strain results of the titanium and zirconia implant models were inserted in a bone block and loaded in the same conditions .

In a systemic review in 2018 on the clinical performance of one-piece zirconia dental implants, they were compared with titanium and two-piece zirconia implant. The review aimed to discuss the limitations encountered with two-piece zirconia implants. The results of the review are inconclusive due to lack of sufficient studies on the long-term success rates of the one-piece zirconia implants, and lack of sufficient comparison between one-piece zirconia implants and titanium implants or two-piece design in different prosthetic conditions [41]. Current studies are mainly concerned with the clinical use of one-piece zirconia implant. Thus, the unavailability of multiple-piece zirconia implants is a limitation in this context [7.[

4- Root analogue Zirconia Implants

Using zirconia as root analogue implants (RAI) is possible and can be successful through the reproduction of the morphology of the removed tooth or teeth. This type of implants replicates the original removed tooth and thus fits normally in the alveolus [4]. RAI aims at replicating the original tooth in terms of peri-implant conditions, stress distribution and aesthetic appearance. The customized implants can keep the stress distribution patterns in the peri-implant bones because their design is identical to the alveolar area [24]. The RAI approach could have several advantages. For example, RAI assures placing implants immediately without complications, decreasing the need for incisions, making patients more comfortable, and minimizing any initial bone loss which could occur because there is no micro gap [24, 42]. RAI has several limitations, and their use is thus exclusive to cases with good periodontal health with appropriate deep socket, absence of periapical disease, nonsurgical extraction and adequate bone support [24]. The notion of using root analogues to substitute for missing teeth is not recent. Ever since 550 BC, there is evidence of some forms of dental implantation including carved wood, metal, shell or stone to mimic the root and be used for implants [29]. The new implant form was initially mentioned in 1809 by Maggiolo, who described an 18-carat root-shaped implant. On the other hand, the use of tooth analogue implant was documented in 1969, but the auto polymerized and heat-processed polymethacrylate used in the manufacture of the tooth analogue were encapsulated by soft tissue rather than Osseo integrated [4, 24, 29]. Lundgren and colleagues reintroduced the idea of root-analogue implants in 1922 [4, 24]. Clinicians recommend that implants have the widest possible platform and be inserted immediately upon extraction to preserve soft-tissue geometry and protect hard-tissue structure [35.[

A new approach for customized 3D printed zirconia RAI through digital light processing was examined. A one partially edentulous mandibular human cadaver was scanned with a cone-beam computed tomography (CBCT) system. The scan volumes and data sets were used to create the CAD model of the RAI. The results revealed observable differences between the RAI optical scans and the original tooth, especially near the apical foramen. This RAI disparity had a maximum deviation of 0.86 mm. the maximum deviation threshold of the 3D-printed RAI surface from the original tooth model and CAD model was set to 0.5. Measurements indicated that 1.55% and 4.86% of the surface areas exceeded the set threshold [42]. Discussion:

This systematic review focused on the development of zirconia implants design throughout the period from 2004 to December 2018. The main focus of the review is the surface of the implant modification and its effect on the implant properties, the number of pieces and their availability in dental implantology, and the root analogue zirconia implant and its favorable time of placement and benefits. A comparative study was conducted to investigate the effect of surface modification on the RTQ of zirconia implants (with two distinct surface types) and sandblasted titanium implants (as a reference) at two-time intervals. The mean RTQ of SLA implants was significantly higher than that of both tested ZrO_2 implants at both four and eight weeks[27].Gahlert et al. [27] have documented similar results when they compared the removal torque of zirconia implants of sandblasted and SLA titanium surfaces [18]. The two materials also showed similar properties when tested after four weeks and twelve weeks of healing and the RTQ values showed a statistically significant increase in the 8th to 12th weeks period. However, the RTQs measured in Gahlert et al.'s (2007) experiment were lower than those measured in this study [27]. This is probably attributable to the surface modification technique applied (acid etching and sandblasting) [1]. On the other hand, two distinct studies were carried out to examine the RTQ values of powder injection moulded (PIM) zirconia implants [25, 31]. The studies indicated that this mechanical testing tends to favor implants with rougher surface profiles due to mechanical interlocking. It is reported that injection moulded zirconia implants show a similar removal torque to RBM titanium implants. The result of this study suggests that injection moulded zirconia implants are a potential alternative to RBM titanium implants in terms of the removal torque.

A one-year prospective cohort study in 2012 investigated the clinical and radiographic outcome of a one-piece zirconia oral implant for single tooth replacement after one year of implantation. This investigation is one of the first prospective cohort reports on one-piece zirconia implants presenting survival rates in addition to bone remodeling/loss and soft tissue parameters. The presented one-piece zirconia implant showed a high risk of crestal bone loss < 2 mm during the first year after placement and, therefore, cannot be recommended for clinical use. However, the cause of such an increase in bone loss is not determined to be the material of the implant itself or other physical or mechanical properties such as geometry, surface or loading mode [37.[

At the same line, in a longitudinal prospective cohort study on one-piece zirconia implants for single tooth substitution, survival rates at three years of the study were found to be inferior to those in reports of similar-shape, immediately loaded one-piece titanium and zirconia implants. Bone remodeling analysis revealed high frequencies of bone loss < 2mm [19]. In terms of the success of bonded or screwed zirconia implant, we have two different results. The first was concluded by a clinical study testing the in-vitro performance of one- and two-piece zirconia implant systems for the anterior application. The experiment showed that bonded two-piece zirconia implant systems exhibited more failure rates and weaker fracture resistance than well-proven screwed two-piece titanium systems and hence may not be acceptable for clinical anterior placement[6].In a recent systematic review, adverse technical and biological outcomes were more commonly encountered when cement adhesive is used instead of screw retention in the restorative system [17]. Another in-vitro study testing the performance of two-piece zirconia implants in the replacement of anterior teeth, however, documented zero failures of the cemented two-part zirconia or the reference titanium systems under accelerated ageing tests. All groups of screw-retained zirconia systems had failures, most of which included fractured abutment and/or implant and some of which had fractured/loosened screws [10]. Survival rates of one-piece zirconia implants were documented in several studies. Grassi et al. recorded 96.9% and 96.7% survival rates after one and five years of the implantation, respectively [5]. In the other two studies [19, 37], survival rates were found to be 90.2% after 3 years and 95.4% after 1 year, respectively. Only one study examining the cumulative survival rate of two-piece implants was reviewed, and the rate was 95.8% after 32.8 months. Therefore, the survival rates are high indicating these implants applicability in implant dentistry.

Upon reviewing several studies on root-analogue zirconia implants [6, 23, 24, 29, 42], the authors reported various advantages of this type of implants. The similar topography to the extracted tooth root saves the dentist and the patient the trouble of bone drilling and traumatic preparation before implant placement. The same authors concluded that introducing significant modifications, such as adding macro retentions and reducing the implant diameter next to the cortical bone, may provide primary stability and excellent osseointegration of immediate root analogue zirconia implants as well as avoid the aesthetically unfavorable bone resorption. However, macro-retentions can only be added in the interdental space to prevent fractures in the buccal cortex. The technique has experimented on multi-rooted teeth in humans and the preliminary results indicate its potential as a substitute for the current immediate implantation methods. New techniques have been described that employ the 3D printing technology in the manufacture of customized zirconia root analogues using digital light processing. This approach may make it possible to manufacture one-piece zirconia (root analogue) implant in advance .

ZrO2 implants have a superior aesthetic appearance to titanium implants, and therefore, they are evaluated for dental use, especially in front teeth. Two of the reviewed studies [21, 27] confirmed that surface characteristics have an important influence on bone integration of ZrO2 implants, even if osseointegration into bone is achieved. However, the surface characteristics of ZrO2 implants still need to be improved. The application of correct surface modifications methods on ZrO2 is expected to give positive biological and mechanical properties that can be comparable to those achieved in titanium SLA implants. To investigate the effect of surface modification on BIC ratio and peri-implant bone formations in zirconia implants, three studies were reviewed [7, 18, 30].They have shown that BIC of sandblasted and sandblasted/etched zirconia surfaces was similar to that of sandblasted/ etched titanium surfaces, indicating the absence of statistically significant difference in osseointegration between the two types of implants. Besides, a study [30] showed that increased BIC and BD percentages should be expected around all splinted implants with immediate loading 3 months after the placement of a micro-grooved zirconia implant. The study also indicated that microgrooves in the intraosseous part of the sandblasted zirconia dental implants increase its BIC and BD in comparison with sandblasted and acid-etched titanium implants and sandblasted zirconia dental implants. In a study [25], it was concluded that (Ti, Zr) O2-coated PIM zirconia implants showed enhanced osteogenesis around the implant compared with uncoated ones regardless of the implant surface roughness. However, mechanical retention (measured through RTQ) was better in rough-surfaced implants regardless of the surface coating. (Ti, Zr) O2 coating caused dramatic changes in the surface topography at the microscopic level, but the improved osseointegration can be attributed to these changes and/or the coating material itself. In the same line, two studies [1, 31] revealed the good effect of surface modification on removal torque of zirconia implant and its possibility to be a good alternative to the titanium implant. One more benefit of surface modification in a zirconia implant is enhancing primary and secondary implant stability, as indicated in one study [28].The same study concludes, through an examination of the implants three months after fixation, that microoving the zirconia implant surfaces provides better primary and secondary implant retention, enhances bone tissue ingrowth and maintains crestal bone level. Using the laser ablation technique in the microgroove formation also minimizes the surface contamination, further promoting these advantageous characteristics. Mechanical retention and biocompatibility are better observed when the whole intraosseous surface of the implants is thus modified. Some of the most important studies that consider the substitution of titanium by zirconia were systematic studies [8, 13, 15-17]. They showed that many in vitro and in vivo studies have proved zirconia implants as a promising alternative to titanium with a superior soft-tissue response, biocompatibility, and aesthetic appearance with comparable osseointegration. Concerning one-piece and two-piece zirconia implants, this review examined several studies that showed the histologic and histomorphometry findings of the two designs [5, 9, 34].They showed that the bone-to-implant contact was high and similar for zirconia and titanium implants after 12 months of osseointegration and 6 months loading period and showed acceptable soft tissue health. Besides, it was concluded that both uncoated and coated zirconia implants can achieve good soft tissue configurations like titanium implants. In these designs, we take the failure rate into considerations. Three studies investigating the in-vitro clinical and histologic performance of two-piece zirconia implants [11, 12, 38] were also reviewed. In a preclinical histometric study [38], the bone integration of two-piece zirconia implants was compared to that of titanium implant having similar surface morphology at four and 16 weeks after implantation. Both types exhibited similar bone integration levels. In the same line, in a two-year prospective cohort study [12] investigating the clinical performance of two-piece zirconia implants with fibreglass in the posterior mandible and maxilla, the implant system was found successful and clinically applicable. A clinical report [11] evaluated the use of a two-piece zirconia implant to replace a single tooth in the anterior maxilla. Six months after implantation, the technique proved successful both clinically and radiographically and patient satisfaction was ensured. This shows that zirconia can be considered as a better alternative to titanium in cases where aesthetic considerations are valued. However, the techniques still require a controlled animal, as well as clinical trials with a long-term evaluation to, be proven for clinical use.

The studies investigating root analogue zirconia implant [23, 24][29] demonstrate the successful clinical use of a modified root-analogue zirconia implant for immediate single tooth replacement. Two-year follow-up of a clinical study [29] indicated that by introducing significant modifications, such as adding macro retentions and reducing the implant diameter next to the cortical bone, may provide primary stability and great osseointegration of immediate root analogue zirconia implants as well as avoid the aesthetically unfavorable bone resorption. In other scoping review on mechanical and biological advantages [24], the time of dental implant placement is determinant on the alveolar bone remodeling. Immediate root-analogue implants might provide a practical solution for the loss of alveolar bone volume without damaging the soft tissues surrounding the implant. The prosthetic outcome is thus functionally improved with satisfactory aesthetic appearance .

Applying zirconia in dental implants as an alternative to titanium is receiving increasing interest due to its favorable optical and biological characteristics. The zirconia-based structure has a convenient color and translucency, while their chemical nature promotes biological anchoring to the bone and soft tissues. Mechanical characteristics of zirconia are evaluated by in vitro tests to predict the longevity of implant-supported prostheses. Biomechanical properties of customized implants can be tested through the finite element analysis to determine the behavior of the implant in different clinical conditions. The analysis can examine the implant material, design, loading and maxillofacial positioning. Custom-made implants provide good stress distribution to the surrounding bone as their geometry is similar to the alveolar region. This, in turn, reduces bone resorption resulting from stress shielding and peri-implantitis. Nevertheless, the absence of periodontal ligament leads to high-stress distribution despite the customized design .

Despite the reviewed studies before and although zirconia can be used as an alternative implant material, one study [22] indicated that the debate is still going and that may properties still require to be established. These include the optimum chemical material composition, implant durability, implant design, the implant-abutment interface, implant-restorative complex, and soft tissue responses. Well planned preclinical studies are needed to evaluate the outcome of zirconia materials and implants before they can be confidently applied in dental practice. Long-term clinical evaluation of zirconia implants is still insufficient, so, the authors recommend caution concerning certain aspects of zirconia implants, such as tensile strength and modulus of elasticity [15.[

5- Conclusion

There are sufficiently significant data on various parameters to conclude that zirconia implants of different sizes, shapes and designs are a promising alternative to titanium in terms of mechanical and biological properties:

-Surface characteristics have an important influence on bone integration of zirconia implants, though osseointegration into bone is evident and surface modification can achieve morphological features that enhance the adsorption of proteins and then the migration of osteogenic cells. In comparison with titanium implants, zirconia implants offer a variety of potential advantages for the use in the esthetic area. Zirconia ceramics are assumed to have the features to prime, initiate and maintain osseointegration as they have no toxic effects on bone tissue. However, further improvements in the surface characteristics of zirconia implants are needed.

-Individual one-piece zirconia systems showed high variations in failure rates and fracture resistance and might, therefore, be applied in anterior regions with limitations. The debate over the superiority of O-PZI to titanium or two-piece implants is not conclusive. Therefore, O-PZI longevity needs to be investigated in clinical studies. They also need to be compared with-PZI and titanium implants in varying prosthetic cases to provide evidence on their clinical effectiveness .

-The Immediate root-analogue implant approach is a potential alternative to immediate replacement after teeth extraction. The technique is almost non-invasive, requiring no bone drilling or traumatic preparation before implantation. With the superior aesthetic outcome, shorter treatment period and lower costs; this method can achieve better patient satisfaction. This type can provide even stress distribution and good force transfer to the underlying bone structure, reducing bone loss around the implants in the early stages of recovery . However, longitudinal studies are still required to evaluate long-term clinical success and to examine any possible technical or biological adversities. Further research analyzing the techniques to prevent ageing and enhance surface characteristics, structure and osseointegration of zirconia implant with different surfaces and designs is also needed. More clinical investigations need to be carried out to detect all relevant technical and biological factors with influence patient satisfaction.

Abbreviations

Al2O3 Aluminum oxide

BIC	Bone to Implant Contact
BII	Bone Implant Interface
CAD	Computer Aided Designing
CBCT	Cone-beam Computed Tomography
CBL	Crestal Bone Loss
CT	Computerized Tomography
FGM	Functionally Graded Materials
mBI	Modified Bleeding Index
mPI	Modified Plaque Index
PD	Probing Depth
PIM	Powder Injection Molded
RAI	Root Analogue Implants
RBM	Resorbable Blast Media
REC	Gingival Recession
RTQ	Removal Torques
Ti-SLA	Titanium Sandblasted and acid-etched
ZrO_2	Zirconium oxide

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