An Overview of Zirconia Dental Implants: Basic Properties and Clinical Application of Three Cases

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Due to the possible aesthetic problems of titanium implants, the developments in ceramic implant materials are increasing. Natural tooth colored ceramic implants may be an alternative to overcome aesthetic problems. The purpose of this article is to give information about the basic properties of dental zirconia implants and present 3 cases treated with two-piece zirconia implants. Two-piece zirconia dental implants, 4.0 mm diameter and 11.5 mm in length, were inserted into maxillary incisor region. They were left for 6 months to osseointegrate. Panoramic and periapical radiographs were obtained and examined for bone-implant osseointegration. During the follow-up period the patients were satisfied with their prosthesis and no complication was observed.

Key Words: dental implants, zirconia, zirconium oxide

INTRODUCTION

Since their introduction over 40 years ago, dental implants have been used to support fixed or removable dentures and have become an established treatment modality.1,2 Pure titanium is generally used for dental implants because of its biocompatibility and suitability for tooling.3,4

Using conventional titanium implants to replace missing teeth may often be perceived through the peri-implant mucosa impairing aesthetic outcomes and can cause an unaesthetic appearance because of the dark colour of titanium.5–7 Also, the implant head may be visible because of soft tissue shrinkage, recessions, and peri-implant lesions.5,8 Further, although titanium has resistance to corrosion, investigations have shown increased titanium concentration in bone near titanium implants9 and in regional lymph nodes—but clinical findings are not yet clear10—and after contact with saliva, galvanic side effect of titanium is also described.11

In the late 1960s, ceramic implants made of Al2O3 (polycrystals or single crystal) have been considered as an alternative treatment for improved aesthetics.12–14 The first ceramic oral implant was crystalline bone screw implants produced by Sandhaus, who later introduced the Cerasand oral implant.13–15 In the middle of the 1970s, the implant known as the “Tübingen Implant (Frialit 1)” was introduced.13,16–20 A decade after the Tübingen Implant, the Bionit implant system and, in the early-to mid-1980s, ceramic anchor implants were produced. Aside from polycrystalline aluminium oxide, single crystal alumina (sapphire)—known as the “Bioceram implant”—has also been used as an implant material.13,21–26 These implants needed large geometric dimensions, so the indication of these implants was limited. However, their surface qualities achieved predictable bone and soft tissue healing.26 Aluminium oxide- or alumina-based implants are osseointegrated well, but they are not available in the market because of their insufficient physical properties during long-term load.12,13

In recent years, zirconia (Y-TZP; yttria tetragonal
zirconia polycrystals), a high strength ceramic material with good long-term results in the field of medical implants, has been suggested as an alternative for dental implants. Y-TZP has higher resilience and flexural strength than aluminium oxide and offers advantages over aluminium oxide for dental implants.\textsuperscript{27–33} Will zirconia implants become an alternative to titanium implants?

**Properties of Zirconia Implants**

Y-TZP is a high strength ceramic material comprised of \( \text{ZrO}_2 \) and \( \text{Y}_2\text{O}_3 \) particles. It forms a stable tetragonal structure at room temperature after sintering. The transformation toughening mechanism is one of the main reasons for the high strength and toughness of Y-TZP.\textsuperscript{28,31,34}

Y-TZP is a bioinert and nonresorbable metal oxide that has excellent resistance to corrosion and wear, Young modulus similar to stainless steel alloy, high flexural strength (900–1,200 MPa), Vickers hardness (1,200) and Weibull modulus (10–12), high fracture resistance, high radiopacity, low thermal conductivity, an ivory color similar to the color of the natural tooth, ability to be machined, light transmitting, and good biocompatibility.\textsuperscript{1,2,7,12,27,28,35–41} Despite these advantages, zirconia can undergo low-temperature degradation that is identified as a surface transformation from tetragonal phase to monoclinic phase in water, water power, or aqueous solutions; this process may affect the microstructure and physical properties of zirconia.\textsuperscript{42} However, preparation and cyclic loading can decrease the fracture strength resistance of the zirconia implants\textsuperscript{34} and fractures can occur in smaller diameters (3.25 mm).\textsuperscript{35}

Exploiting advances in nanotechnology, Ce-TZP/\( \text{Al}_2\text{O}_3 \) nanocomposite has been introduced, offering superior mechanical properties compared to conventional Y-TZP,\textsuperscript{43–45} but there are not any published data on using Ce-TZP/\( \text{Al}_2\text{O}_3 \) nanocomposite as a dental implant base material.

Zirconia has been shown to be as biocompatible as titanium.\textsuperscript{46,47} Biocompatibility is defined as the biomaterial or its degradation products that are not responsible for inflammatory reactions.\textsuperscript{28} Zirconium oxide provokes less reaction in tissues than do other restorative materials, such as titanium.\textsuperscript{46} Degidi et al\textsuperscript{47} confirmed this result and reported that the level of the bacterial products measured with nitric oxide synthase, inflammatory infiltrate, microvessel density, and vascular endothelial growth factor expression were found higher around the titanium caps than around the \( \text{ZrO}_2 \) ones. Zirconia can up- or down-regulate gen expressions, so zirconia can be a self-regulatory material that can modify turnover of the extracellular matrix.\textsuperscript{48}

Direct contact between the implant and surrounding bone is a parameter of clinical success.\textsuperscript{28} Animal studies have demonstrated that zirconia implants showed direct bone apposition, and it has been concluded that osteoblastic cells have good proliferation and surface attachment to zirconia.\textsuperscript{1,2,12,26,29,49}

Hoffmann et al\textsuperscript{2} evaluated the zirconia implant bone interface histologically in rabbits. Four zirconia and 4 titanium implants were placed. The area of bone-implant contact was evaluated, and the results demonstrated a similar rate of bone apposition on zirconia and surface-modified titanium implant surfaces during early healing.\textsuperscript{2}

In 2 animal studies, Depprich et al\textsuperscript{1,29} investigated the osseointegration of zirconia implants. The results showed that there was no osseointegration difference on zirconia implants with modified surfaces and titanium implants with a similar surface topography.\textsuperscript{1,29} Histological results showed direct bone contact on the zirconia and titanium surfaces. It was demonstrated that zirconia implants with modified surfaces resulted comparable osseointegration with titanium implants.\textsuperscript{1} Gahlert et al\textsuperscript{49} confirmed these results in an histomorphometrical study. In another study, Gahlert et al\textsuperscript{26} investigated 2 different zirconia surfaces (machined and sandblasted) topographies biomechanically and histologically with titanium sandblasted and acid-etched surfaces. Thirteen adult miniature pigs received 78 implants. After a healing period of 4, 8, and 12 weeks, implants were subjected to removal torque tests and then analyzed for direct bone apposition under a light microscope. The results showed that surface topography affected the osseointegration period. The acid-etched and sandblasted titanium surfaces had the highest removal torque values, and the machined zirconia surfaces had the lowest values.

Kohal et al\textsuperscript{12} investigated the biomechanical and histological behavior of zirconia implants in rats. Four groups of implants were evaluated: machined zirconia implants, zirconia implants with a roughed
surface, machined titanium implants, and titanium implants with an electrochemically roughened surface. The results showed that all tested zirconia and titanium implant surfaces were biocompatible and osseoconductive. Surface modification of zirconia implants showed no difference with the electrochemically modified titanium implant surface when the histological and biomechanical results were compared.\textsuperscript{12}

Kohal et al\textsuperscript{50} evaluated the osseointegration of custom-made zirconia and titanium implants. Twelve custom-made zirconia and 12 custom-made titanium implants were inserted in extraction sites in 6 monkeys. The titanium implants were sandblasted and acid etched; the zirconia implants were only sandblasted. Six months after the implant insertion, single crowns were made and, after 5 months delivery of the crowns, the implants with the surrounding hard and soft tissue were harvested. No statistically significant differences were found in soft tissue when the results evaluated under the light microscope. The connective tissue attachment (distance between the apical end of the junctional epithelium and first bone-to-implant contact) were similar; however, titanium implants showed a greater extension. The mean mineralized bone-to-implant contacts after a 9-month healing period were 72.9\% for titanium implants and 67.4\% for zirconia implants.

Animal studies showed similar osseointegration values for zirconia implants in comparison with titanium implants, but these studies have limited numbers of samples and include only the short-term histological results.\textsuperscript{12,26,29,49} Long-term examinations of zirconia implants are limited to establish their clinical performance and success.

Payer et al\textsuperscript{51} evaluated clinical and radiographic outcomes of immediately provisionalized one-piece zirconia implants (WhiteSKY). A total of 20 implants were inserted in 20 patients. Observed bone loss was 1.29 mm after the 24-month follow-up period. In another study, Kohal et al\textsuperscript{52} investigated the clinical and radiographic outcomes of ZI Unite (Nobel Biocare, Gothenburg, Sweden) one-piece zirconia implants after a 1-year follow-up. The marginal bone loss was 1.31 mm, and the survival rate was 95.4\%.

Only the immediate loaded one-piece implants were investigated in these studies\textsuperscript{51,52}, and it was concluded that there was not any problem on the osseointegration of zirconia implants but the observed bone loss was higher than 0.2 mm, which was reported as an implant success criteria for titanium implants after 1 year by Smith and Zarb.\textsuperscript{53} Long-term clinical study results with two-piece titanium implants showed higher success rate and lower bone resorption when compared with one-piece zirconia implants.\textsuperscript{54–56}

Biocompatibility of the zirconia has been proven in several animal investigations, but there are insufficient studies focusing on the physical properties of zirconia implants.\textsuperscript{12,34}

Çağlar et al\textsuperscript{57,58} investigated the one-piece zirconia implants in 2 biomechanical studies: In the first, the titanium and yttrium-stabilized zirconium implants were compared in three-dimensional finite element analysis. The zirconia implant generated the lowest stresses in cortical bone, and the zirconia abutment resulted in lower vonMises and compressive stresses than did the titanium abutment in implant and cortical bone.\textsuperscript{57} In the second study, 3 different zirconia dental implants were compared, and the higher stresses were evaluated.\textsuperscript{58}

Silva et al\textsuperscript{6} tested influence on fatigue reliability and failure modes between as-received and after crown preparation on one-piece ceramic implants. Forty-eight one-piece Y-TZP ceramic implants were evaluated. Results showed that crown preparation did not influence the reliability of the one-piece ceramic implant, and fatigue did not influence the lifetime of ceramic implants at loads under 600 N.\textsuperscript{6}

In another study, Gahlert et al\textsuperscript{35} investigated the failure of fractured zirconia dental implants. In this study, 170 implants were inserted in 79 patients, and the results showed that fracture rate of nearly 10\% within a follow-up period of 38 months after prosthetic loading. Ninety-two percent of the fractured implants were in reduced diameters (diameter 3.25 mm). These diameter-reduced implants cannot be recommended for clinical use. The cracks were located in 10 of 13 fractured implants at the level of the first turn of the threads, and it was indicated that zirconia implants used in this study osseointegrated well.\textsuperscript{35} Kohal et al\textsuperscript{27} also investigated that biomechanical requirements of zirconia implants restored with different all-ceramic crowns for clinical use. All-ceramic crowns were cemented on zirconia implants and exposed to the artificial mouth. The fracture strength of the all-ceramic
implant crown systems was evaluated. Conventional titanium implants restored with porcelain-fused-to-metal crowns served as control group. It was demonstrated that zirconia implants restored with the crowns possibly achieve the biomechanical requirements for anterior teeth.27

**Zirconia Oral Implant Systems**

Zirconia oral implants have been used for several years.59 Immediate, non-submerged, root-analogue, anatomic zirconia implants can be custom-made and used in selected cases.61,62 The surface treatments for zirconia implants can be machined,12 mechanically ground,3 nano technology surface modified (CaP nanolayer),63 bioactive ceramic coated (calcium phosphate, bisphosphonate and collagen),3,40 acid etched,3,49 and sandblasted.49

Currently, 9 Y-TZP zirconia implant systems are commercially available: (1) the SIGMA (Incermed, Lausanne, Switzerland) with various Sigma implant designs, (2) the Z-Systems (Oensingen, Switzerland) with its Z-Look3 implant, (3) the Bredent (Bredent Medical, Senden, Germany) with the White Sky implant system, (4) the Ziterion with one-piece the Zit-Z and two-piece Zit-vario (Ziterion, Uffenheim, Germany), (5) the Relmpant system (Relmpant, Hagen, Germany), (6) the Goei system (Goei Inc, Akutsu-Hiroshima, Japan), (7) the Konus system (Konus Dental, Bingen, Germany), (8) the CeraRoot System (Oral Iceberg, Granollers, Barcelona, Spain) with the Ceraroot’s one-piece zirconia implant system,34,40 and (9) the Zeramex implant system (Dentalpoint AG Swiss Implant Solutions, Zurich, Switzerland).

Zirconia implants can be manufactured as one-piece or two-piece designs.3,5,34,59 One-piece systems are in one part, inserted during the surgery. The transmucosal part of one-piece implants is integrated with the implant. Two-piece systems are submerged during the first surgery, and the transmucosal part is connected to the implant during second surgical procedure.64

**One-piece zirconia implants**

Using one-piece implants for everyday practice provides flapless surgery with minimal surgical invasion and benefits soft tissue preservation.7 Especially in the anterior region, one-piece implants must be placed at perfect anatomical position to establish aesthetic appearance of the restoration.42 One minor surgery—placing healing caps—can be avoided, so it is unnecessary to wait for the healing of the soft tissue after the second surgery.65 The treatment time can be shortened.65 Therefore, no clinical data were found for bone augmentation or guided bone regeneration procedure with one-piece implants.42,64

The location of the margin of the one-piece implant supported prosthetic restoration can be defined by intraoral preparation.42 However, it has been reported that grinding Y-TZP ceramic can effect monoclinic phase transformation and introduce microcracks that negatively influence the mechanical properties.34,42 Andreiotelli and Kohal7 reported that in vitro preparation of zirconia implants has a statistically significant negative influence on the fracture strength of the implants. Furthermore, screw joint complications are avoided with one-piece implants. Repair of the fractured implant is not possible when the implant head is fractured.7 Another benefit of one-piece implant design is that the implant can be inserted and immediately restored with a provisional crown,7 which may effect the patient positively.

**Two-piece zirconia implants**

Two-piece zirconia implants are preferable when optimal implant stability is not achieved at the implant placement. Bone augmentation procedures can be used with the two-piece implants.42,65 The bone-implant interface is important for modeling and remodeling of bone. Movements in bone-implant interface after implantation may affect the early remodeling and osseointegration.66,67 Transmitting unwanted loading forces to the healing bone can be minimized with the use of two-piece implants.65 Two-stage procedure minimizes the risk of infection because the implant is submerged and peri-implant tissue is separated from the oral microbial environment.64

The biomechanical information on two-piece zirconia implants is limited to one in vitro study.67 In this study, Kohal et al59 evaluated the stability of prototype two-piece zirconia and titanium implants after artificial aging. The results showed that biomechanical stability of all tested implant groups was borderline for clinical use. A high number of failures occurred during the artificial loading in the titanium group at the abutment screw level, and
the zirconia implant groups showed irreparable implant head fractures at low fracture load. In an animal study, Kohal et al.50 investigated the osseointegration of the loaded custom-made two-piece zirconia and titanium implants. The results demonstrated that there was not any statistically significant difference between the 2 types of implants, and the custom-made zirconia implants showed the same peri-implant soft tissue dimensions.

The purpose of this article is to give information about the dental zirconia implants and present 3 cases treated with two-piece zirconia implants located in the anterior maxillary region.

**Clinical Applications**

The patients in this article were referred to the Department of Prosthetic Dentistry at Gazi University, Faculty of Dentistry. After clinical and radiographic examinations, zirconia implants were decided to be inserted because of the esthetic expectations of the patients. Oral and written explanations of the treatment—including risks, benefits, and alternative therapies—were provided. The patients volunteered for this treatment and signed an informed consent form based on the Helsinki Declaration, revised in 2008.

Cylindrical screw type subgingival, platform-switched two-piece zirconia implants (Zit-vario; Ziterion), 4.0 mm diameter and 11.5 mm in length, were inserted into maxillary incisor region. Implant surgery was performed by the same surgeon.

The implant surgical procedures were performed with local anesthesia (Ultracain DS Forte, Aventis, Istanbul, Turkey). The zirconia implants were left in place for 6 months to osseointegrate. During this period, the patients presented wearing an interim removable prosthesis, replacing the missing dentition. The patients were seen 15 days postsurgery, and sutures were removed.

After a 6-month healing period, panoramic and periapical radiographs were obtained and examined for bone-implant osseointegration. The implants were uncovered, the cover caps were removed, and the suitable abutments were chosen. The abutments were cemented into the implant with a self-adhesive universal composite cement (RelyX Unicem, 3M ESPE, Seefeld, Germany), recommended by the abutment manufacturer. Excess cement was pressed out and removed from the implant-abutment interface. During the soft tissue healing period, the patients presented wearing a provisional fixed prosthesis, replacing the missing dentition. After a 2-week healing period of the soft tissue, an elastomeric impression material (Zeta Plus, Zhermack, Badia Polesine, Italy) was used to take the impression. After the milled zirconia frameworks try-in, definitive restorations were cemented on the implant using self-adhesive universal composite cement (RelyX Unicem, 3M ESPE). The restorations were left out of occlusion, and contacts in lateral excursions were avoided. After setting of the cement, any remnants were removed. The patients received oral hygiene maintenance instructions.

**Case 1**

A 23-year-old man was referred to our clinic with an endodontical failure of his maxillary left lateral incisor (Figure 1). Because of the patient’s esthetic expectations, a zirconia implant was chosen to be inserted. The implant site prepared for the implantation, and it was examined for bone fenestrations or dehiscences after site preparation. A bone defect was observed on the buccal region. The buccal defect area was filled with a xenogeneous bone graft (Bio-Oss, Geistlich Biomaterials, Wolhusen, Switzerland). Abutment connection was performed 6 months following implant insertion. The values of the plaque control record (PCR), bleeding on probing (BOP), and probing depth (PD) were measured after the cementation of definitive restoration and a 1-year follow-up period (Figure 2). The PCR, BOP, and PD values were compared, and the marginal bone level was evaluated by taking standardized periapical radiographs. Peri-implant marginal bone loss was observed on the mesial crestal area at the end of a 1-year follow-up period (Figure 3).

**Case 2**

A 43-year-old woman with a missing left central maxillary tooth was referred to our clinic (Figure 4). In spite of routine treatment, a two-piece zirconia implant was placed into the maxillary anterior region. The implant was uncovered, and the abutment was connected 6 months following implant insertion. The planning abutments were used for choosing the suitable abutment. An aesthetic and functional result was achieved with the zirconia crown (Figures 5 and
6). Peri-implant lesion, soft-tissue recession, or prosthetic complications were not observed after a 1 month follow-up period.

**Case 3**

A 25-year-old woman with a missing right central tooth that had been fractured in a traffic accident (Figure 7) was referred to our clinic. The periapical radiography showed no apical lucency in the area of the missing tooth (Figure 8). A two-piece zirconia implant was placed into the maxillary anterior region. After a 6-month osseointegration period (Figure 9), a 15 degree angled zirconia abutment was chosen, prepared, and cemented onto the implant (Figure 10). After using a provisional crown for 2 weeks, a definitive zirconia crown was made and cemented (Figures 11 and 12). The patient was satisfied with the aesthetic and functional results.

**DISCUSSION**

Investigations suggest that zirconia ceramics are highly biocompatible and have sufficient mechanical properties to be used as dental implant base material.* Careful case selection is very important when using zirconia implants. To achieve successful aesthetic results with implant supported restorations in the esthetic zone, advance planning for accurate and adequate placement of the implants is a requirement. In addition to high mechanical properties of the zirconia implants, long-term clinical studies must be performed for clinical acceptability and consideration as an alternative to titanium implants. Clinical studies with zirconia implants is very limited; only a few one-piece and two-piece zirconia implant case reports have been published.

The clinical investigations and case reports related with zirconia implants started in the last decade. In 2004, Kohal et al presented the first two-piece zirconia implant case report. A custom-made zirconia implant was inserted in the patient and after a 6-month healing period, the single all-ceramic crown was cemented onto the implant. It was demonstrated that zirconia implants would be offered for an esthetic restoration of missing teeth.

In 2006, Mellinghoff reported the clinical results of zirconia implants. In this study, 189 implants were inserted in 71 patients and examined. The 1-year survival rate of the implants was 93%. In another 1-year follow-up study, 100 one-piece zirconia dental implants were investigated in

*References 1, 2, 6, 12, 27, 29, 34, 35, 39, 45, 58, 59.
humans with 2 different rough surfaces by Oliva et al. The overall implant success rate after 1 year of follow-up was 98%. Oliva et al, Sierraalta et al, and Aydın et al presented aesthetic replacement of the maxillary incisors and presented a maxillary anterior partially edentulous space restored with one-piece zirconia implants. The patients functioned successfully with their prostheses and were satisfied with the final results. In another clinical report, Oliva et al demonstrated the usage of zirconia oral implants in a titanium allergy patient. Full-mouth oral rehabilitation using zirconium oxide dental implants were presented, the patient was satisfied with the prosthesis. It was reported that zirconia implants can be used in titanium allergy patients.

In a long-term clinical study, Oliva et al investigated the success of one-piece zirconia implants. A 5-year success rate of 831 zirconia dental implants were evaluated in humans. One-piece zirconia dental implants with 3 different roughened surfaces were designed and manufactured for this study: coated, uncoated, and acid etched. The success rate of the acid-etched surface group was significantly better than the other groups. The results showed that the overall implant success rate after 5 years of follow-up was 95%.

Further, in 2011, Nevins et al reported the histological and clinical evaluations of a two-piece zirconia implants and compared them with the titanium implants. Four titanium and 2 zirconia implants were placed in a healthy woman. One two-piece zirconia implant was displaced for biopsy after 6 months. Clinical and radiographic observations showed that both zirconia and titanium implants achieved osseointegration. Gingival tissues were healthy, and excellent vertical bone height was demonstrated in the radiographs. Histologic observations demonstrated that the bone-to-implant contact with a zirconia implant surface was sufficient to provide clinical and histologic evidence of osseointegration. It was concluded that zirconia implants provided appropriate conditions for soft and hard tissue healing.
The purpose of this article is to give information about zirconia oral implants and to present cases treated with two-piece zirconia implants, but only short-term success of a new two-piece zirconia implant was evaluated. Using zirconia implants can be offered for esthetic restorations of anterior missing teeth, but investigations focusing on the long-term clinical success rate of zirconia implants are necessary.

CONCLUSIONS

Based on the review of literature, it is concluded that zirconia implant systems are a new addition in implant dentistry and may become an alternative to titanium with more natural color. Cases in this article presented a two-piece zirconia implant located in anterior maxillary region. In short-term evaluation, the radiographic and clinical outcomes were successful, and the patients were satisfied with the final result; however, to properly evaluate the two-piece implant’s clinical performance and recommend them for routine clinical use, well-planned controlled animal investigations and clinical trials must be performed with a long-term follow-up.

REFERENCES


33. Helmer JD, Driskell TD. Research on bioceramics. Symposium on Use of Ceramics as Surgical Implants, 1969. Clemson University, Clemson, SC.


