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ORIGINAL ARTICLE

Comparison of implant versus tooth-supported zirconia-based single crowns in a split-mouth design: a 4-year clinical follow-up study

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Abstract
Objectives This study aims to evaluate the 4-year clinical performance of tooth versus implant-supported single-unit zirconia crowns (LAVA™) placed on posterior region.
Materials and methods Twenty-four patients (10 men and 14 women) who had received 48 single crowns (24 implant-supported and 24 tooth-supported) from January 2007 to December 2009, were included. California Dental Association (CDA) quality assessment system, plaque and gingival index scores were used to evaluate the performance of the crowns at baseline and at all follow-up examinations.
Results During the follow-up period, no fracture of zirconia coping has occurred. Major complication was chipping in three patients that required a new crown fabrication. Except for the failure ones, all crowns in both groups were rated as satisfactory at the follow-up examinations based on the CDA quality assessment criteria. There were no statistically significant differences between tooth and implant-supported crowns in terms of periodontal parameters.
Conclusions The present 4-year follow-up clinical study demonstrates that single-unit tooth- and implant-supported zirconia crowns have similar prosthetic and periodontal outcomes.
Clinical relevance Single-unit implant or tooth-supported zirconia crowns may be considered acceptable treatment modalities for restoration of either missing or compromised posterior teeth

Keywords Zirconia · Follow-up study · Dental implants · Clinical · All ceramic

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Introduction

Metal-ceramic crowns have been used for decades and are regarded as the gold standard for fabrication of both tooth- and implant-supported restorations. However, the major disadvantages of these restorations are often related to esthetic or clinical complications, such as reduced translucency, gray reflection through gingival margin, and allergic or even toxic reactions due to the metal substructure [1]. In recent years, with the increasing demand for better esthetics and biocompatibility, all-ceramic single crowns became more popular. Yet, the lower fracture toughness and bending strength of the early-introduced materials resulted in failures, especially in posterior regions [2].

In the early 1990s, a dense material with monocrystalline homogeneity—zirconia—was introduced into dentistry, and has garnered remarkable interest in the biomedical sciences, due to the material's favorable physical, mechanical, biological, and chemical properties, including low thermal conductivity, low corrosion potential, and good radiopacity [3, 4].

The introduction of yttria-stabilized tetragonal zirconia polycrystal has allowed high-strength zirconia to be used for fabrication of fixed partial prostheses in load-bearing regions [5]. The tetragonal polycrystalline zirconia exhibits high flexural strength (900–1200 Mpa) and fracture toughness values, owing to a phase transformation toughening mechanism [6]. The promising performance of zirconia is supported by numerous studies, in which after 3 to 5 years of loading, the

posterior zirconia-based restorations showed excellent survival rates, ranging from 97.8 to 100 % [7–10]. Moreover, 10-year clinical outcomes of fixed dental prostheses with zirconia frameworks have been reported as having a 91.5 % survival rate [11].

The successful use of computer-aided design/computer-aided manufacturing (CAD/CAM) technology for the fabrication of tooth-supported restorations has encouraged clinicians to extend zirconia's application to implant-supported restorations. The single implant-supported restoration is a much-desired option for the treatment of missing teeth, especially in the anterior region. Commercially, pure titanium has been widely used as an abutment material and represents the gold standard in implant therapy because of its well-documented biocompatibility and its mechanical properties that support fixed implant-supported restorations [12, 13]. Thus, zirconia-based restorations may be preferable to metal-ceramic restorations fabricated on titanium abutments, due to zirconia's higher biocompatibility and better esthetic results.

Despite its favorable properties, one of the drawbacks for zirconia-based restorations is the material's low-temperature degradation. This aging phenomenon is described as spontaneous slow transformation from the tetragonal phase to the more stable monoclinic phase in zirconia grains at relatively low temperatures (150–400 °C) in humid environments [14]. Another drawback of the zirconia-based restorations is chipping (cohesive failure of the veneering ceramic) [15], one of the most common technical complications [8, 16, 17]. This type of failure mode indicates a mismatch of the coefficients of thermal expansion, and an insufficient interfacial bond between the core and the veneer materials, which has also been confirmed by recent in vitro shear bond test results [18, 19].

In recent years, several clinical trials and reviews have been published on implant-retained single crowns. In a systematic review of 26 studies examining a total of 1558 implants, Jung et al. [20] evaluated the survival rates and incidences of complications for implant-supported single crowns. Five-year survival of implant-supported single crowns was 94.5 %; the survival of metal-ceramic crowns was significantly higher than that of all-ceramic crowns ($p = 0.005$). Controversy still arises regarding the long-term stability of zirconia, as well as the use of zirconia as a substitute for alloys in implant dentistry.

Due to the absence of the periodontal ligament around dental implants, occlusal stress can be greater on implant-supported restorations than on tooth-supported restorations, and thus, stress can be conducted directly to the bone [21, 22]. Larsson et al. [23] reported greater incidences of chipping in implant-supported zirconia restorations. Therefore, one may suggest that the clinical outcomes of tooth- and implant-supported single zirconia crowns are comparable. In this regard, the purpose of this clinical study was to compare the biological, technical, and esthetic outcome of tooth- and implant-supported zirconia single crowns using the California Dental Association (CDA) quality evaluation system and periodontal parameters [24].

Material and methods

In the present study, the clinical outcomes of implant- and tooth-supported zirconia-based single crowns were evaluated in 24 patients with a split-mouth design.

Study design

The study was conducted by two prosthodontists (MBG, UC) in the clinics of both a private practice and the Faculty of Dentistry, Hacettepe University, Ankara, Turkey. The study protocol was approved by the Committee on Research Ethics of Hacettepe University (GO 14/72-19). The criteria for patient selection are shown in Table 1. Excessive parafunctional activity was not considered exclusion criteria. The patients were fully informed about the purpose and design of the study by the treating dentists, and informed consent was obtained prior to treatment. The plaque index (PI) and the gingival index (GI) of the patients were improved to "0" before implant placement [25, 26]. This study is based on data from 24 patients (10 men and 14 women) with 48 implant- and tooth-supported zirconia-based single crowns. The mean age was 44.1 ± 11.4 years (range, 30–64 years) at the time of crown cementation. The data referring to the missing and the restored teeth are presented in Table 2. Patient records, from January 2007 to December 2009, were evaluated by the

Table 1 Criteria for patient selection

Each participant must
1. Have upper or lower, premolar or molar loss in 1 quadrant and indication of crown fabrication for the symmetrical vital or devital tooth in the same jaw.
2. Understand the purpose of this study and agree to participate in follow-up examinations for up to 5 years.
3. Not have contraindications for oral implant treatment (e.g., uncontrolled diabetes, metabolic bone disorders, history of radiotherapy in the head and neck, current chemotheraphy, or other diseases with an influence on bone healing).
4. Have good oral hygiene and low caries activity.
5. Have natural dentition of opposing teeth
6. Not have tooth mobility; active bone resorption, furcation involvement, or peri-apical pathology of the supporting teeth;
7. Have an extensive loss of tooth structure indicating fabrication of full crown.
8. Not have a history of drug abuse and/or life-threatening diseases (ASA classification)

Table 2 Distribution of 48 zirconia crowns by region

Region	Tooth ($n = 24$)	Implant ($n = 24$)
Maxillary premolar	14, 15, 25, 25, 24, 24	24, 25, 15, 14, 15, 15
Mandibular premolar	44, 45, 45, 34, 35, 35	35, 35, 34, 45, 44, 45
Maxillary molar	16, 16, 17, 26, 16, 26	27, 27, 26, 17, 27, 16
Mandibular molar	36, 47, 46, 46, 37, 46	46, 36, 37, 36, 47, 37

authors in November 2013. The number of patients who participated in this study was primarily driven by the duration of the study period and the number of referrals of eligible patients that fit the inclusion criteria.

Treatment procedure

Twenty-four implants (Astra Tech Ossesospeed® implants; Astra Tech AB, Mölndal, Sweden) were inserted according to standard surgical guidelines from the manufacturer. After a healing period of 3 months for mandibula and 6 months for maxilla, implant- and tooth-supported zirconia-based single crowns were fabricated by two experienced prosthodontists (MBG, UC).

The tooth preparations symmetrical to the implants were made in a standardized manner with an occlusal/incisal clearance of 1.5 to 2 mm. The axial reduction was 1.5 to 2 mm, with an 8° to 10° taper. A circumferential chamfer finish line was prepared using a torpedo-formed cylindrical diamond bur, approximately 0.5 to 1 mm subgingivally. Impression copings were attached to the implants, and retraction cords were placed around prepared teeth. Complete arch impressions were made with a polyether impression material (Impregum/Permadyne; 3M ESPE AG, Seefeld, Germany), and master models were obtained.

The prefabricated titanium abutments (TiDesign™, Astra Tech AB, Mölndal, Sweden) were all prepared with a circumferential chamfer finish line located 0.5 to 1 mm subgingivally. For both implant- and tooth-supported crowns, zirconia copings (LAVA™; 3M ESPE, St. Paul, MN) were manufactured out of pre-sintered zirconia blocks using the CAD/CAM technique according to the manufacturer's recommendations. The zirconia cores were designed with an anatomic form and a minimum thickness of 0.5 mm to provide a homogeneous support for the veneering ceramic. A feldspathic porcelain, Vita VM®9 (Vita Zahnfabrik, Bad Säckingen, Germany), was fused to the cores, and the veneer thickness layer was between 1.0 and 2.0 mm. Proximal and occlusal contacts were adjusted as necessary for maximum intercuspation. The same laboratory (Dental Estetik, Ankara, Turkey) manufactured all the bilayer zirconia crowns, and one company fabricated all the zirconium oxide cores (LAVA™; 3M ESPE). All abutments were screw retained onto the implants, with a defined screw torque of 25 Ncm in accordance with the manufacturer's recommendations. The crowns were provisionally cemented with an eugenol-free temporary cement (Provicol, Voco GmbH, Cuxhaven, Germany) for 2 weeks before definitive cementation. Prior to definitive cementation, the inner surfaces of the crowns were air abraded with 50-μm alumina particles at 0.25 MPa [27] and cleaned using an ultrasonic cleaner. A resin-modified glass ionomer cement (GC Fuji Plus; GC Corporation, Tokyo, Japan) was used for definitive cementation of the crowns. Patients were instructed about maintenance and oral hygiene procedures at the time of crown cementation and at each follow-up appointment.

Data collection

All patients were recalled and examined by one of two authors at the time of cementation (baseline), at 6 months, and at yearly follow-up appointments for 4 years.

Each restoration was assessed in terms of marginal integrity, surface, color, and anatomic form according to the CDA quality evaluation system. The clinical and radiological assessments were performed by an observer (GA) not involved in patient treatment. According to CDA rating criteria, crowns were rated as excellent, acceptable, and unacceptable (correction or replacement). The periodontal health status around both implant- and tooth-supported crowns and the oral hygiene were assessed by recording the PI [28] and the GI [28] at four aspects of the abutments. The digital peri-apical radiographs were taken using the paralleling technique with film holders at the follow-up examinations, and the marginal bone levels at the implants were assessed for the most coronal bone-implant contact, both mesially and distally. In addition, biological complications (e.g., pain, loss of vitality, need of endodontic treatment, secondary caries) in tooth-supported zirconia crowns, and both biological and mechanical complications (peri-implantitis, pain, loosening or fracture of the abutment screw, and loss of retention) in implant-supported zirconia crowns were recorded during the clinical follow-up examinations. Fracture of the zirconia copings and major chipping (not repairable) was considered failures.

Statistical analysis

Statistical analysis was performed using SPSS version 21.0 (SPSS Inc., Chicago, IL). The PI and GI values were compared by using Wilcoxon signed ranks test, set at a significance level of $p < 0.05$. The mean differences between the GI values at baseline and at the 4-year follow-up were detected as 0.30 (standard deviation, 0.50). A difference can be detected at an alpha level of 0.05, with a statistical power of 80.36 % by enrolling 48 teeth. The minimum post hoc statistical power between statistically different groups was 80.36 %. Power

calculation was performed using the NCSS PASS 11 program (NCSS LLC, Kaysville, UT).

Results

Success rates of zirconia crowns

The success rates of molars were 91.7 and 95.9 % in implant- and tooth-supported zirconia crowns, respectively. During the follow-up period, no zirconia coping fractures occurred; however, major chipping (not repairable) was detected in three patients. The chippings were detected in one maxillary and one mandibular implant molar and in one tooth-supported mandibular molar after 2, 4, and 3 years, respectively. In the premolar region, the success rate was 100 %, and no biological or mechanical complications were recorded for either group.

Success and survival rates of dental implants

All implants survived, and no mobility was recorded after 4 years of function. The survival rate was 100 % at the end of the study period. No complications were detected in either the abutments or the abutment screws. In four cases, slight grayish mucosal discoloration occurred due to the titanium-prefabricated abutment. The mean calculated marginal bone loss between the baseline and the 4-year follow-up was less than 1 mm (0.7 ± 0.9 mm).

Biological and mechanical complications of tooth-supported zirconia crowns

No mechanical or biological complications were detected in either group. No secondary caries, no loss of retention, and no need for endodontic treatment were detected in the tooth-supported zirconia crowns during the 4-year follow-up period.

CDA quality evaluation

The results of the CDA ratings are presented in Table 3. The crown rated "not acceptable" was due to veneer chipping that required the remake of the restoration. Marginal integrity at baseline was excellent, at 83.3 and 87.5 % in the tooth and the implant groups, respectively. At the 4-year follow-up, these percentages had decreased to 66.6 and 74 % in the tooth and the implant groups, respectively, and the excellent-rated anatomic form values had declined 8.4 and 12.5 % in the tooth and the implant groups, respectively. When color and surface were evaluated at baseline, 83.3 and 75 % of the crowns were rated as excellent based on the CDA in the tooth and the implant groups, respectively; these percentages decreased to 62.5 and 54.1 % in the tooth and the implant groups, respectively, after 4 years. Further, except the failed crowns, the marginal integrity, the anatomical form, the color, and the surface ratings of crowns in both groups were rated excellent or acceptable according to CDA criteria after 4 years.

Table 3 Quality of zirconia crowns at the 4-year follow-up period based on the CDA (%)

	Excellent		Acceptable		Unacceptable	
	Tooth	Implant	Tooth	Implant	Tooth	Implant
Margin integrity						
Baseline	20 (83.3)	21 (87.5)	4 (16.6)	3 (12.5)	–	–
1 year	18 (75)	20 (83.3)	6 (25)	4 (16.6)	–	–
2 years	16 (66.6)	19 (79.1)	8 (33.3)	4 (16.6)	–	1 (4.1)
3 years	16 (66.6)	19 (79.1)	7 (29.1)	4 (16.6)	1 (4.1)	–
4 years	16 (66.6)	18 (75)	7 (29.1)	4 (16.6)	–	1 (4.1)
Anatomic form						
Baseline	18 (75)	15 (62.5)	6 (25)	9 (37.5)	–	–
1 year	17 (70.8)	15 (62.5)	7 (29.1)	9 (37.5)	–	–
2 years	17 (70.8)	14 (58.3)	7 (29.1)	9 (37.5)	–	1 (4.1)
3 years	16 (66.6)	12 (50.0)	7 (29.1)	11 (45.8)	1 (4.1)	–
4 years	16 (66.6)	12 (50.0)	7 (29.1)	10 (41.6)	–	1 (4.1)
Color and surface						
Baseline	20 (83.3)	18 (75)	4 (16.6)	6 (25)	–	–
1 year	19 (79.1)	17 (70.8)	5 (20.8)	7 (29.1)	–	–
2 years	16 (66.6)	16 (66.6)	8 (33.3)	7 (29.1)	–	1 (4.1)
3 years	15 (62.5)	14 (58.3)	8 (33.3)	9 (3.5)	1 (4.1)	–
4 years	15 (62.5)	13 (54.1)	8 (33.3)	9 (37.5)	–	1 (4.1)

Periodontal outcome

Plaque index

The average PI scores for tooth-supported zirconia single crowns and implant-supported zirconia single crowns both at 6 months and at the 1-, 2-, 3-, and 4-year evaluations were 0.3 ± 0.6, 0.3 ± 0.5, 0.5 ± 0.5, 0.6 ± 0.3, and 0.7 ± 0.6 and 0.2 ± 0.5, 0.3 ± 0.2, 0.3 ± 0.5, 0.4 ± 0.5, and 0.5 ± 0.6, respectively. When comparing the 4-year results with the baseline data, the scores were significantly higher at the year 4 follow-up for both groups ($p < 0.001$) However, there were no significant differences between implant-supported and tooth-supported crowns ($p > 0.05$).

Gingival index

The average GI scores for tooth-supported zirconia single crowns and for implant-supported zirconia single crowns at 6 months and at the 1-, 2-, 3-, and 4-year evaluations were 0.2 ± 0.2, 0.2 ± 0.3, 0.4 ± 0.3, 0.5 ± 0.4, and 0.6 ± 0.5 and 0.1 ± 0.1,

0.2 ± 0.2, 0.4 ± 0.5, 0.4 ± 0.6, and 0.5 ± 0.6, respectively. The scores were significantly higher at the 4-year follow-up for both groups ($p < 0.001$). However, there were no significant differences between implant-supported and tooth-supported crowns at the 4-year recall when compared with the baseline values ($p > 0.05$).

Discussion

In this clinical study, the biological, technical, and esthetic outcome of implant- and tooth-supported single zirconia crowns in the same individual were compared using the CDA quality evaluation system during 4 years of follow-up. The obtained results indicate that prosthetic and periodontal responses were similar for both implant- and tooth-supported single zirconia crowns. We detected no coping fractures. For zirconia copings, fracture toughness values ranged between 5.5 and 7.4 MPa, which are much higher than other all-ceramic core materials. Because of the unique transformation toughening mechanism and the superior fracture resistance of zirconia, coping fractures are infrequent [2]. However, fractures due to trauma, parafunctional habit, and insufficient coping thickness have been reported in clinical studies [29–33]. Although it is not a definite assumption, the results of the present study did not present a correlation between zirconia copings and fracture in terms of either implant or tooth support.

The most critical problem related to zirconia-based crowns was chipping, which has been observed in previous clinical studies [9, 34–36]. Tsumita et al. [37] detected chipping in posterior zirconium oxide-based, fixed, partial dentures (14.3 %) in their prospective clinical study but reported that there were no further problems after polishing the porcelain veneer. In the present study, non-repairable cohesive failures of the veneering ceramic were detected in functional cusps of three molar crowns. None of the affected patients were bruxers or had ceramic restorations of the opposing teeth.

Even though most veneering ceramics have low fracture toughness values (0.7–0.9 MPa $m^{1/2}$), which are eight times lower than that of the base zirconia due to their main glass compositions, these materials present esthetic advantages and are still widely used in clinical practice [38]. Theoretically, the use of monolithic zirconia may be preferred in fabrication of molar crowns if esthetics is not the major concern. In their short-term clinical study, Batson et al. [39] presented acceptable results of single-unit, posterior, CAD/CAM, monolithic zirconia crowns without any fracture; however, long-term results are essential to clarify the survival of this material. In addition, the relationship between the thickness of the veneering porcelain and the fracture strength under applied tensile strength must be studied in order to design a better core framework and minimize the incidence of chipping.

The high reliability of zirconia for abutments and framework materials in implant-supported restorations has been confirmed by clinical studies [23, 36]. However, higher chipping rates for layering porcelain in multi-unit, implant-supported, zirconia-based restorations (10–40 %) than for multi-unit, tooth-supported restorations have been reported [23, 31, 40]. This result was associated with the absence of the periodontal ligament around dental implants, and thus occlusal stress could have been conducted directly to the bone [21, 22]. There have been inconsistencies between the results obtained from a number of previous studies and results of our study regarding the statistically insignificant differences in survival rates of both implant- and tooth-supported molars. On the other hand, in another study on 40 single-unit, implant-supported zirconium dioxide crowns, three chippings were reported, but neither implant loss nor coping fractures occurred, which supports our results regarding single-unit zirconia crowns [41].

At the 4-year follow-up examination, all crowns were rated satisfactory according to the CDA quality evaluation system, except the ones in which chipping occurred. Marginal integrity was rated "excellent" for both supporting types. This finding is in line with the results of other studies of all-ceramic crowns [42, 43]. In their in vitro study, Karatasli et al. [44] reported superior marginal fit for CAD/CAM LAVA zirconia copings compared with those created using the Celay and the Zirkonzahn systems. The "excellent" score for anatomic form was low in implant-supported crowns compared with tooth-supported crowns. This could be attributed to under-contour, related to the prefabricated abutments used for molar crowns. Custom abutments may lead to better anatomic contour ratings [45].

Although zirconia systems are widely preferred for fabrication of implant- or tooth- supported restorations, there are limited numbers of long-term studies regarding the clinical outcome of implant-supported, zirconia-based restorations. The present study specifically explores the clinical outcome of both implant- and tooth-supported zirconia-based single crowns, in a split-mouth design to minimize possible inter-individual variability.

The changes in the PI and GI scores were very low over time, and the differences between implant- and tooth-supported crowns were insignificant. For both groups, no gingival enlargement, gingival recession, pocket formation, bleeding on probing, suppuration, or pain was detected in terms of periodontal parameters, as seen in other studies [36, 46]. This may be related to improving PI and GI to "0" before implant placement, as well as consistent oral hygiene motivation during the follow-up period. One of the limitations of this study is the lack of PI and GI scores obtained from a non-restored tooth to serve as a control value. Nevertheless,

Tsumita et al. [37] did not present significant differences between control and study groups of teeth.

Zirconia-based restorations are primarily preferred for their esthetic advantages [47]. Therefore, recent studies have concluded that rating esthetic properties is an important component of successful treatment [36, 46]. In the present study, the use of titanium abutments instead of zirconia abutments resulted in slight grayish mucosal discoloration in four cases, which may be considered another limitation of this study. In clinical situations where the mucosal thickness is 2 mm or less, in contrast to zirconia abutments, titanium abutments may cause a change in color of the peri-implant mucosa [48].

With regard to biological complications, none of the tooth-supported crowns experienced secondary caries, hypersensitivity, or endodontic treatment during the follow-up period. Further, none of the implant-supported crowns experienced biological complications, and the marginal bone loss of less than 1 mm was consistent with the results of Mertens et al. [49], which indicated that the mean crestal bone loss amounted to 0.3 ± 0.72 mm during a 5-year period.

Although the results of the present study encourage the use of zirconia for single-unit, implant- and tooth-supported restorations, one should consider the limited number of the crowns evaluated when interpreting the present results.

Conclusions

Within the limitations of this study, single-unit, implant- or tooth-supported zirconia crowns have similar prosthetic and periodontal outcomes, and both may be considered acceptable treatment modalities for the restoration of missing or compromised posterior teeth. However, taking into account the small number of patients, further studies with larger numbers of patients and longer follow-up periods are needed to compare the effectiveness of zirconia-based restorations.

Compliance with ethical standards

Conflict of interest Mustafa Barış Güncü declares that he has no conflict of interest. Umut Cakan declares that he has no conflict of interest. Guliz Aktas declares that she has no conflict of interest. Güliz Nigar Güncü declares that she has no conflict of interest. Şenay Canay declares that she has no conflict of interest.

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Ethical approval The study protocol was approved by the Committee on Research Ethics of Hacettepe University (GO 14/72-19).

Informed consent Informed consent was obtained from all participants prior to treatment.

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