CLINICAL SCIENCE

A 3-year follow-up study of all-ceramic single and multiple crowns performed in a private practice: a prospective case series

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OBJECTIVES: Zirconia-based prostheses are commonly used for aesthetic crown and fixed restorations, although follow-up data are limited, especially for implant-supported crowns. The aim of this study was to evaluate the three-year clinical results of the installation of 463 zirconia core crowns by a general dental private practice.

METHODS: This study followed 142 patients (69 men and 73 women; aged 28-82 years) who had received 248 single crowns (202 tooth-supported, 36 implant-supported) and 225 multiple units of up to six elements (81 tooth-supported, 144 implant-supported). Clinical events, including fracture and loss of retention, secondary caries, and marginal integrity, were recorded. The overall failure rate was computed for the fractured and lost prostheses. Aesthetic, functional, and biological properties were rated, and patient satisfaction was investigated.

RESULTS: During the three-year follow-up period, four patients were lost from the study (18 crowns, 4% of the total crowns). Three of the zirconia prostheses suffered fractures in more than three units (11 crowns; one- vs. three-year follow-up, $p<0.05$, Wilcoxon signed-rank test), and the cumulative prosthesis survival rate was 98.2%. Twelve units lost retention and were re-cemented, and no secondary caries of the abutment teeth were reported. The aesthetic, functional, and biological properties were generally well-rated, and there were no differences between tooth- and implant-supported crowns. The lowest scores were given regarding the anatomical form of the crowns, as some minor chipping was reported. Relatively low scores were also given for the periodontal response and the adjacent mucosa. Overall, patient satisfaction was high.

CONCLUSIONS: At the three-year follow-up, the zirconia-core crowns appeared to be an effective clinical solution as they had favorable aesthetic and functional properties. Only the marginal fit of the prostheses should be improved upon.

KEYWORDS: Zirconia; Prostheses; Implants; All-ceramic crowns; Clinical performance.

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INTRODUCTION

Porcelain-fused-to-metal (PFM) restorations have been the prevailing technology for aesthetic crown and fixed-prosthesis restorations for approximately 50 years.[1] However, the failure of these restorations is often related to technical or clinical problems, such as ceramic breakage fractures from the metal substructure, or aesthetic complications, such as the unnatural appearance of the prosthesis.

To overcome these problems, dental ceramics have been used as alternatives to metallic dental restoration. Feldspathic ceramics have met patient aesthetic demands but do not provide adequate structural integrity, especially for the posterior teeth. With the development of crystalline ceramics, alumina and zirconia came into use for prosthetic reconstructions; these were first used for orthopedics and later for dentistry.[2-5] Overall, from a mechanical perspective, prosthetics composed of oxide/crystalline ceramics are superior to those made with feldspathic/glass ceramics,[6,7] and these are considered a viable alternative to PFM restorations.[2,5,8-12]

Zirconia is a crystalline dioxide of zirconium. In particular, yttrium-oxide-partially-stabilized zirconia (3Y-TZP) has mechanical properties very similar to those of metals, yet it has a color similar to that of teeth.[3,4,13] Its mechanical properties, which are similar to those of stainless steel, allow

No potential conflict of interest was reported.

for a substantial reduction in core thickness.[4] Cyclical stresses are also well tolerated by this extremely biocompatible material.[2-4,9]

Exposure to moisture for an extended period of time, even at the low temperatures found in the mouth, can have a detrimental effect on the properties of zirconia.[13] Therefore, zirconia crowns should be covered by ceramics to increase their resistance towards the conditions of the oral cavity.[3,13]

Coloring salt solutions can be added to zirconia without altering its microstructure, color, flexural strength, or aging resistance.[13] A shaded zirconia core, which has a more natural appearance with an opaque, yellow dentin overlaid by translucent enamel, provides greater aesthetic results.[10,13]

Zirconia-based prostheses can be used for both single- and multiple-unit crowns that are anchored on either implants or teeth.[1,7,8,10-12,14-16] However, there have not been a significant amount of data published regarding a comparison of long-term clinical results from the use of different kinds of zirconia-based crowns, particularly for patients who have attended private dental practices. Indeed, most published studies have been laboratory-controlled investigations,[1,17,18] and the majority of these clinical evaluations have reported data on small numbers of patients.[7,8,11,12,19] An extensive review of the relevant literature was recently performed by Denry and Kelly,[2] who reported that the largest published comprehensive series included 68 patients who were rehabilitated with 81 total prostheses and were followed for four-five years. Only the studies from Ortorp et al.[16] and Encke et al.[15] followed a larger number of patients, but they analyzed only single crowns fixed on teeth. Schley et al.[5] reviewed studies on tooth-supported fixed prostheses and analyzed 330 zirconia-based fixed prostheses over a minimum follow-up period of three years. From this review, only one study was conducted in a private practice, and the other nine were performed at universities.

Two types of problems have been reported in the literature: biological and technical. Among the biological issues, many studies have reported caries and loss of tooth vitality, whereas the loss of retention and the chipping or fracturing of veneers have been the most frequently reported as technical complications.[5,7,12,16] Additionally, marginal degrees of adaptation together with mediocre or inadequate periodontal conditions have been observed.[8,15]

The aim of the current clinical follow-up study was to evaluate the three-year clinical results of a large number of zirconia-core crowns that had been installed at a general dental private practice. Both single crown and multiple crown units, supported by either teeth or implants, were followed-up with for this study.

MATERIALS AND METHODS

Patient selection

This study consisted of a clinical follow-up examination of 142 patients who had been given single- or multiple-unit zirconia crowns at a general private practice in Italy. One hundred and forty two patients (69 men, 73 women), who were between 28 and 82 years of age (mean age 49.2 years, SD 13.4) and had received zirconia crowns between January 2005 and January 2006, were recalled to be evaluated during the follow-up between January 2009 and August 2009 by two independent evaluators (GMT, ES). Four patients were lost to follow up for various reasons (deceased, no contact, or moved). The inclusion criteria consisted of having received a zirconia crown from the same private practice during the aforementioned time span.

Clinical procedures for zirconia crowns

All patients had indications for one or more, one to three-six unit fixed dentures supported by either implants or teeth.

All of the patients were examined for oral hygiene by a dental hygienist and were found to have moderate or good oral hygiene with less than 25% marginal plaque. These patients also had low or moderate caries activity, with less than five new restorations during the preceding five-year period. Good general health without severe medical or psychological conditions was generally self-reported by patients. Preliminary dental treatment was performed to obtain the aforementioned inclusion criteria. All subjects provided informed consent for the clinical procedures, as required by current Italian law.

For tooth-supported prostheses, preliminary clinical examinations found that the bone level of the supporting teeth was at least half the root length and was without signs of active bone resorption, furcation involvement, mobility, or periapical pathology. Furthermore, the residual coronal tooth structure was shown to have a tooth restorability index value equal to or less than 2.[20]

All teeth were root-canal treated or non-surgical re-root canal-treated and received prefabricated posts. A core was built using a composite material (LuxaCore, DMG Hamburg Germany) if the occlusal space had more than 2 mm of centric occlusion.

All of the tooth preparations were made in a standardized manner. The occlusal reduction was 2 mm, and the axial reduction was 1.5 to 2 mm. There was also a 10-degree taper made that followed the scalloping of the free gingival margins. For aesthetic reasons and for a sound tooth structure, the facial side taper was located 0.5 mm deep subgingivally with a supragingival lingual side.

Each of the multiple three-six units had a total gap that was equal to but did not exceed the crown-root surface area of the abutment teeth compared to the teeth to be restored. Moreover, these had at least 3 mm of occlusogingival height from the col of the interproximal papilla to the marginal ridge of the prospective abutments adjacent to the space to be restored.[19]

For implant-supported prostheses, all of the implants (Titanmed, Milde Implants, Bergamo, Italy) displayed good osseous integration in both the clinical and radiographic tests. Implant abutments (titanium) were prepared according to the principles outlined for teeth.

In terms of crown thickness, the core generally supports a uniform thickness of veneering ceramic, and there should be a maximum of 2 mm of unsupported porcelain. Polyether (Impregum/Permadyne, 3M ESPE AG, Seefeld, Germany) was used for the impressions in a customized tray (Apex trays, Megadenta Dentalprodukte Radeberg, Germany). Individualized, provisional resin crowns (Takilon BB, Salmoiraghi srl, Melegnano, Lodi, Italia) were cemented using a temporary zinc oxide-eugenol (ZOE) cement (Temp Bond, Kerr Italia, Scafati, Salerno, Italia). A plaster model (Esthetic-base gold, Dentona AG, Dormund, Germany) was obtained and used to create an anatomical contour wax-up.

The wax contour was then impressed on the plaster model. The plaster model, the silicone mask, and then both components together were scanned with a laser scanner (Everest Scan pro, Kavo, Biberach, Germany).

The zirconia core was designed with respect to the ceramic support. A computer-aided manufacturing (CAM) device milled the zirconia core in the pre-sintered state (Zirite, Keramo, Tavernerio, Como, Italia) and then sintered it according to the manufacturer's instructions (TRF, Udine, Italia). Feldspathic porcelain (CZR Noritake Kizai Co. Ldt, Nagoya, Japan) was fused to the core with zirconium oxide margins (Figure 1) by a master ceramist (SST Dental Lab, Segrate, Italy). Proximal contact points and occlusal contacts were adjusted as necessary for maximum intercuspation and to avoid interference from the lateral excursions. The abutment teeth or implants were cleaned prior to cementation. For final cementation, a glass-ionomer cement was used (Ketac, 3M ESPE AG, Seefeld, Germany).

A final control step after cementation was performed using a surface electromyographic (EMG) analysis under static conditions to verify the equilibrium of the neuromuscular system.[21] As described by Ferrario et al.,[21] the right and left side masseters and the temporalis anterior muscles of each patient were analyzed during maximum voluntary jaw clenching. From the EMG standardized potentials, the percentage overlapping coefficient (POC), an index of neuromuscular symmetry, was computed. For all of the patients, POC indices greater than 85% were found, which corresponded to the values previously reported for patients with good neuromuscular equilibrium.[21]

Data collection and analysis

Following the EMG control analysis, the patients were scheduled for oral-hygiene appointments at six-month intervals and were asked to contact the clinic if they experienced any problems with their prostheses. Additionally, the patients were examined by a dentist for follow-up at 12, 24, and 36 months after the procedure and before their scheduled oral hygiene appointments. These recall appointments were standard for patients at this private practice.

For each patient, data were collected regarding the patient's sex, age at the time of crown placement, number of crowns cemented, and the tooth or implant position. Also, clinical findings, including fracture or loss of retention of the prosthesis, secondary caries, marginal integrity, wear or surface roughness, and aesthetic characteristics, were recorded. The overall failure rate was computed for fractured and lost prostheses.

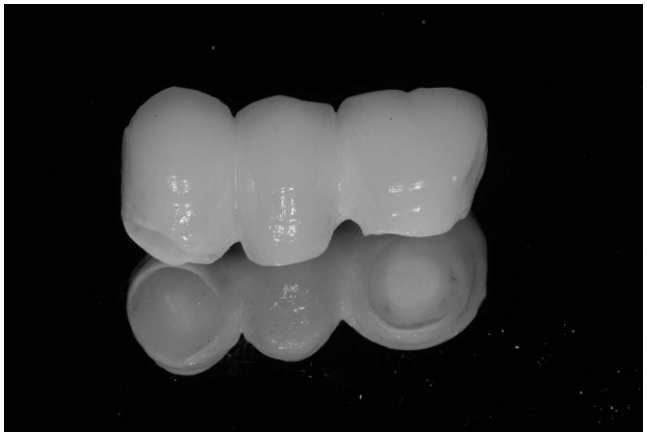

Figure 1 - Three-unit, all-ceramic prostheses for 14-16 rehabilitation crowns for implants. The zirconia core was surrounded by feldspathic ceramic.

In accordance with a study by Hickel et al.,[22,23] the aesthetic, functional and biological properties of the analyzed crowns were rated. The aesthetic properties examined included surface luster and staining, color stability and translucency, and anatomic form. The functional properties that were scored included the existence of fractures, retention, marginal adaptation, contact points and their impact on chewing food, and radiographic aspects. The biological properties scored postoperatively included sensitivity of the endodontically treated teeth, loss of osseointegration for the implants, the recurrence of caries, erosion, abfraction, periodontal and mucosal aspects of the restored teeth, and oral and general health.

The overall clinical evaluation was stratified according to the following five levels: clinically excellent/very good (A); clinically good (B); clinically sufficient/satisfactory (minor shortcomings without unacceptable defects but not adjustable without damaging the tooth) (C); clinically unsatisfactory but reparable (D); and clinically poor (necessary replacement of the prosthesis) (E). The overall aesthetic, functional, and biological scores were also compared across the acceptable (excellent, good, and sufficient scores) and the unacceptable (unsatisfactory and poor scores) categories.

Patient satisfaction regarding both the aesthetics and the function of the zirconia prostheses was assessed using a questionnaire with five possible rating categories: (A) excellent/very good, the patient was entirely satisfied, and the prosthesis could not be detected with the tongue; (B) good, the patient was entirely satisfied, but the prosthesis could be detected with the tongue; (C) sufficient/satisfactory, aesthetic shortcomings and/or discomfort during chewing were reported, but a replacement was not necessary; (D) poor, the patient requested an improvement to be made to the prosthesis; and (E) unsatisfactory, the patient was completely dissatisfied and required a new prosthesis but declined replacements of the same type or made of the same material.[22,23]

Different groups of dentists comprised the evaluator and operator groups. A training session for the evaluators occurred prior to scoring. Inter-examiner agreement for the examined characteristics was 92% at the beginning of the study, 90% at 12 months, and 88% at 36 months.

The clinical (aesthetic, functional, and biological properties) scores and the patient satisfaction scores obtained at the one- and three-year recall visits were compared using the Wilcoxon signed-rank test, and these were examined separately for the single- and multiple-unit crowns and for the implant- and tooth-supported crowns. The significance level was set to 5% ($p<0.05$).

RESULTS

A total of 238 single crowns were installed in 108 patients (56 women and 52 men). Of these, 202 tooth-supported single crowns were installed in 96 patients (51 women and 45 men), and 36 implant-supported single crowns were installed in 19 patients (9 women and 10 men) (Table 1).

A total of 225 multiple-unit crowns (up to six elements) were installed in 34 patients (24 women and 10 men). Of

Table 1 - Distribution of the single- and multiple-unit zirconia crowns on teeth and on implants by region.

	Single crowns		Multiple-unit crowns	
	Teeth	Implants	Teeth	Implants
Anterior	33	5	27	26
Posterior	159	31	54	118
Total	202	36	81	144

these, 81 tooth-supported zirconia crowns were placed in 14 patients (8 women and 6 men), and 144 implant-supported crowns were placed in 29 patients (13 women and 16 men).

There were two men and four women who received both single- and multiple-unit tooth-supported restorations, four men who received both single- and multiple-unit implant-supported restorations, and nine men and 11 women who received both tooth- and implant-supported zirconia restorations in various combinations. Overall, a total of 463 single or multiple-unit crowns (up to six elements) were installed in 142 patients (67 women and 75 men).

Most of the crowns were placed in the premolar to molar area (n = 362; 78%), and 59% of the crowns were tooth-supported (n = 213). Fifty-one percent of the crowns were positioned in 68 women, and there was an average of 3.5 crowns per patient (with a maximum of 21 in a 51-year-old patient). For male patients, there were an average three crowns cemented per patient (with a maximum of 20 in a 66-year-old patient).

All single crowns and bridges were in use at the recall appointments one- and two-years post-implantation. Of the 142 patients who had received zirconia crowns three years prior to the recall appointment, four patients had been dropped from the study for various reasons (deceased, no contact, or moved), and these patients represented a total of 18 crowns (4% of the total crowns).

The crowns that were deemed lost to follow-up and the cumulative survival rate (CSR) are presented in Table 2.

During the follow-up period, no core material in the single-, double-, or triple-unit crowns fractured. In three of the zirconia prostheses that had more than three units, we observed fractures at the interdental connectors or at the zirconia core near the connectors. There were 12 tooth-supported units that lost retention, and these included one 5-unit prosthesis, one 4-unit prosthesis, and three single-tooth prostheses. Each of these was able to be re-cemented. No secondary caries of the abutment teeth were reported. In all patients, the zirconia crowns were occluded against teeth or fixed dental prostheses (Tables 3, 4).

At each of the recall visits (one, two, and three years post-procedure), the aesthetic, functional, and biological properties received high ratings for almost all of the crowns examined, and the ratings were equivalent for both the tooth- and implant-supported crowns. Also, no patients reported symptoms related to periapical periodontitis during the follow-up period.

Table 2 - Crowns lost to follow-up and the cumulative survival rate (CSR).

Time	Examined crowns	Lost to follow-up	Failed	CSR (%)
Crown cementation	463	0	0	100
1 year	463	0	0	100
3 years	445	18	11	98.2

Patient satisfaction with the zirconia crowns was also generally high. From a clinical point of view, the lowest scores were obtained in the aesthetic category and were related particularly to the anatomical form of the crowns and the existence of some minor chipping (Figure 2). Relatively low scores were also obtained in regards to the biological properties (for the sub-categories of periodontal response and adjacent mucosa) as more than half of the crowns received only sufficient/satisfactory scores (Figure 3). The scores were generally higher for crowns on anterior teeth and for single crowns.

The overall aesthetic and biological clinical scores for the analyzed zirconia prostheses were universally acceptable (445 crowns, 100%). In general, the aesthetic and biological ratings did not change during the period of analysis. In contrast, the overall functional score was not acceptable for 23 crowns (5.2%) due to fractures or a loss of retention (most were multiple-unit prostheses on posterior teeth). These scores were significantly higher at the 12-month follow-up visits than at the 36-month follow-up visits for both implant- and tooth-supported crowns (Wilcoxon signed-rank test, implant-supported, $p<0.001$; tooth-supported, $p=0.002$).

DISCUSSION

In this clinical follow-up study, a three-year follow-up analysis was performed to assess more than 400 zirconia core crowns supported either by teeth or implants. The number of prostheses included in this study was larger than most previously published studies; for example, this current study was approximately two to four times larger than those reported by Ortorp et al.[16] and Encke et al.[15] The number of tooth-supported prostheses (283) was comparable to that reviewed by Schley et al.[5]

To the best of our knowledge, this is the first investigation to analyze the long-term outcomes of implant-supported zirconia prostheses. Furthermore, in previous studies, only zirconia prostheses with up to five elements were longitudinally followed, whereas we included several six-element units that were both implant- and tooth-supported. For example, one prior laboratory investigation that tested zirconia prostheses with only as many as five units found that these can withstand main chewing and clenching stresses.[3] Furthermoe, only the study from Papaspyridakos and Lal[10] described a 12-unit mandibular prosthesis, although this study did not examine longitudinal data regarding their rehabilitation performance.

In this private-practice study, the loss of patients at the time of follow-up was minimal, as only 4% of the prostheses were unavailable for analysis at the three-year recall visit. Previous studies have documented much larger drop-out frequencies, including 10%,[5] 13%,[15] 17%,[16] and 24%.[7] The higher participation rate of our patients is in line with their high satisfaction towards the zirconia core prostheses.[7,16] Perhaps the inclusion of patients from a private practice where the patient-dentist relationship is influenced by monetary considerations contributes to general satisfaction.

According to the results of our study, only 11 crowns fractured during the time period analyzed, and each of these fracture events occurred between the two- and three-year follow-up visits. As expected, the prostheses with a

Table 3 - Clinical evaluation of the analyzed single-crown zirconia prostheses, according to Hickel et al.[22] at the three-year follow-up examination. All values represent the number (and percentage) of prostheses.

Clinical evaluation single crowns	Position	Support	A	B	C	D	E
Aesthetic properties							
Surface luster	Anterior	Implants	0	5 (100)	0	0	0
		Teeth	0	39 (100)	0	0	0
	Posterior	Implants	0	31 (100)	0	0	0
		Teeth	0	145 (100)	0	0	0
Surface staining	Anterior	Implants	5 (100)	0	0	0	0
		Teeth	39 (100)	0	0	0	0
	Posterior	Implants	31 (100)	0	0	0	0
		Teeth	145 (100)	0	0	0	0
Color stability and translucency	Anterior	Implants	0	5 (100)	0	0	0
		Teeth	0	39 (100)	0	0	0
	Posterior	Implants	0	31 (100)	0	0	0
		Teeth	0	145 (100)	0	0	0
Anatomic form	Anterior	Implants	0	5 (100)	0	0	0
		Teeth	0	39 (100)	0	0	0
	Posterior	Implants	0	0	31 (100)	0	0
		Teeth	0	0	145 (100)	0	0
Functional properties							
Fractures and retention	Anterior	Implants	5 (100)	0	0	0	0
		Teeth	39 (100)	0	0	0	0
	Posterior	Implants	31 (100)	0	0	0	0
		Teeth	142 (98)	0	0	3 (2)	0
Marginal adaptation	Anterior	Implants	5 (100)	0	0	0	0
		Teeth	39 (100)	0	0	0	0
	Posterior	Implants	31 (100)	0	0	0	0
		Teeth	145 (100)	0	0	0	0
Contact point/food impact	Anterior	Implants	5 (100)	0	0	0	0
		Teeth	39 (100)	0	0	0	0
	Posterior	Implants	31 (100)	0	0	0	0
		Teeth	138 (95)	0	7 (5)	0	0
Radiographic examination	Anterior	Implants	5 (100)	0	0	0	0
		Teeth	39 (100)	0	0	0	0
	Posterior	Implants	31 (100)	0	0	0	0
		Teeth	145 (100)	0	0	0	0
Patient's view	Anterior	Implants	5 (100)	0	0	0	0
		Teeth	31 (79)	8 (21)	0	0	0
	Posterior	Implants	9 (29)	22 (71)	0	0	0
		Teeth	61 (40)	84 (60)	0	0	0
Biological properties							
Postoperative (hyper-) sensitivity*	Anterior	Implants	5 (100)	0	0	0	0
		Teeth	39 (100)	0	0	0	0
	Posterior	Implants	31 (100)	0	0	0	0
		Teeth	145 (100)	0	0	0	0
Recurrence of caries, erosion, abfraction	Anterior	Implants	5 (100)	0	0	0	0
		Teeth	39 (100)	0	0	0	0
	Posterior	Implants	31 (100)	0	0	0	0
		Teeth	145 (100)	0	0	0	0
Periodontal response	Anterior	Implants	0	5 (100)	0	0	0
		Teeth	0	39 (100)	0	0	0
	Posterior	Implants	0	29 (94)	2 (6)	0	0
		Teeth	0	97 (67)	48 (33)	0	0
Adjacent mucosa	Anterior	Implants	5 (100)	0	0	0	0
		Teeth	39 (100)	0	0	0	0
	Posterior	Implants	0	30 (97)	1 (3)	0	0
		Teeth	7 (5)	98 (67)	40 (28)	0	0
Oral and general health	Anterior	Implants	5 (100)	0	0	0	0
		Teeth	39 (100)	0	0	0	0
	Posterior	Implants	31 (100)	0	0	0	0
		Teeth	145 (100)	0	0	0	0

Anterior: incisors, canines; Posterior: premolars, molars.
A: clinically excellent/very good; B: clinically good; C: clinically sufficient/satisfactory; D: clinically unsatisfactory; E: clinically poor.
*All the teeth were endodontically treated. For implants, we evaluated loss of osseointegration.

greater number of units were more fragile than the single crowns. Fractures were found only in prostheses with more than three units and were located at the interdental connectors or in the zirconia core adjacent to the connectors, in accordance with published findings.[2,7] Nevertheless, these 11 crowns represented only 9% of the total multiple-unit (four to six) crowns, which indicated that multiple-unit zirconia core prostheses demonstrated greater clinical

Table 4 - Clinical evaluation of the analyzed multiple-unit zirconia prostheses, according to Hickel et al.[22] at the 3-year follow-up examination. All values represent the number (and percentage) of prostheses.

Clinical evaluation multiple units	Position	Support	A	B	C	D	E
Aesthetic properties							
Surface luster	Anterior	Implants	0	26 (100)	0	0	0
		Teeth	0	27 (100)	0	0	0
	Posterior	Implants	0	118 (100)	0	0	0
		Teeth	0	54 (100)	0	0	0
Surface staining	Anterior	Implants	26 (100)	0	0	0	0
		Teeth	27 (100)	0	0	0	0
	Posterior	Implants	118 (100)	0	0	0	0
		Teeth	54 (100)	0	0	0	0
Color stability and translucency	Anterior	Implants	0	26 (100)	0	0	0
		Teeth	0	27 (100)	0	0	0
	Posterior	Implants	0	118 (100)	0	0	0
		Teeth	0	54 (100)	0	0	0
Anatomic form	Anterior	Implants	0	26 (100)	0	0	0
		Teeth	0	9 (33)	18 (67)	0	0
	Posterior	Implants	0	0	118 (100)	0	0
		Teeth	0	0	54 (100)	0	0
Functional properties							
Fractures and retention	Anterior	Implants	26 (100)	0	0	0	0
		Teeth	27 (100)	0	0	0	0
	Posterior	Implants	111 (94)	0	0	0	7 (6)
		Teeth	41 (76)	0	0	9 (17)	4 (7)
Marginal adaptation	Anterior	Implants	26 (100)	0	0	0	0
		Teeth	27 (100)	0	0	0	0
	Posterior	Implants	118 (100)	0	0	0	0
		Teeth	54 (100)	0	0	0	0
Contact point/food impact	Anterior	Implants	26 (100)	0	0	0	0
		Teeth	27 (100)	0	0	0	0
	Posterior	Implants	118 (100)	0	0	0	0
		Teeth	54 (100)	0	0	0	0
Radiographic examination	Anterior	Implants	26 (100)	0	0	0	0
		Teeth	27 (100)	0	0	0	0
	Posterior	Implants	118 (100)	0	0	0	0
		Teeth	54 (100)	0	0	0	0
Patient's view	Anterior	Implants	10 (38)	16 (62)	0	0	0
		Teeth	9 (33)	18 (67)	0	0	0
	Posterior	Implants	0	118 (100)	0	0	0
		Teeth	0	54 (100)	0	0	0
Biological properties							
Postoperative (hyper-) sensitivity*	Anterior	Implants	26 (100)	0	0	0	0
		Teeth	27 (100)	0	0	0	0
	Posterior	Implants	118 (100)	0	0	0	0
		Teeth	54 (100)	0	0	0	0
Recurrence of caries, erosion, abfraction	Anterior	Implants	26 (100)	0	0	0	0
		Teeth	27 (100)	0	0	0	0
	Posterior	Implants	118 (100)	0	0	0	0
		Teeth	54 (100)	0	0	0	0
Periodontal response	Anterior	Implants	0	0	26 (100)	0	0
		Teeth	0	0	27 (100)	0	0
	Posterior	Implants	0	0	118 (100)	0	0
		Teeth	0	0	54 (100)	0	0
Adjacent mucosa	Anterior	Implants	0	0	26 (100)	0	0
		Teeth	0	0	27 (100)	0	0
	Posterior	Implants	0	0	118 (100)	0	0
		Teeth	0	0	54 (100)	0	0
Oral and general health	Anterior	Implants	26 (100)	0	0	0	0
		Teeth	27 (100)	0	0	0	0
	Posterior	Implants	118 (100)	0	0	0	0
		Teeth	54 (100)	0	0	0	0

Anterior: incisors, canines; Posterior: premolars, molars.
A: clinically excellent/very good; B: clinically good; C: clinically sufficient/satisfactory; D: clinically unsatisfactory; E: clinically poor.
*All the teeth were endodontically treated. For implants, we evaluated loss of osseointegration.

performance in this study than in previous studies with the same follow-up period.[16] All of these fractures occurred in prostheses of posterior teeth, which is where most of the multiple-unit crowns were placed, and this is similar to that reported by previous studies that examined prostheses at all locations within the mouth.[2,11,12,16]

After a one-year follow-up period, Encke et al.[15] reported partial fractures in 4% of the single crowns on posterior

Figure 2 - Minor chipping of the anterior zirconia prosthesis on tooth 11.

teeth. After a two year follow-up period, Vult von Steyern et al.[11] reported minor chip fractures in 15% of their three- to five-unit posterior prostheses. After a three year follow-up period, Sailer et al.[7] reported that four out of 33 three- to five-unit posterior prostheses needed to be replaced due to technical problems (poor cementation, fracture, or porcelain chipping). From a four-year follow-up study, Wolfart et al.[12] reported a 12 to 13% complication rate due to technical problems. In the current study, 12 units lost cementation, but each could be re-cemented, as seen in previous studies.[12]

In comparison to previously published reports, the current study observed a lower incidence of veneer chipping and fractures. Several technical and clinical aspects of the study may have contributed to this success rate. Sailer et al.[7] emphasized the need for refined zirconia veneers, as surfaces made with crystalline ceramics have a higher fracture rate than do those made with feldspathic ceramics. For the patients in this study, feldspathic porcelain was fused to solid zirconia prostheses, which

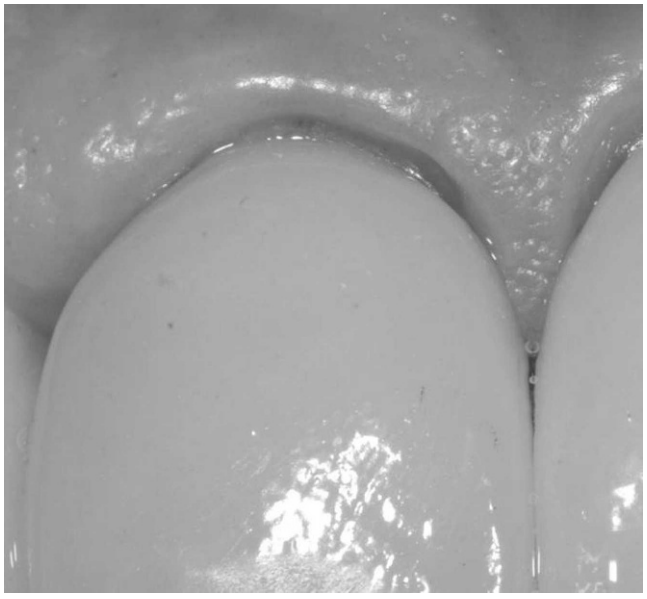

Figure 3 - Poor gingival response at the 1-year follow-up.

reduced the likelihood of this occurrence. Additionally, each of the crowns in this study had a sufficient ceramic thickness.[15] From a clinical point of view, it was critical that occlusal reduction during preparation be meticulously verified, as suggested by previous investigations.[15] In addition, no occlusal adjustments were deemed necessary,[15] which may have been related to the proper functioning of the prostheses, as the surface EMG analysis found that all patients had good neuromuscular equilibrium and that the new occlusal conditions had been properly incorporated into the stomatognathic system.[21] A strict relationship between neuromuscular equilibrium and variations in occlusal characteristics has been previously described.[24,25]

For 81% of the crowns analyzed by this study, the anatomical form was scored as sufficient or satisfactory, although no cases were scored as excellent. To avoid fractures in the zirconia prostheses, the occlusion adjustments were made after cementation and during maximum voluntary clench. Evidently, minimum and direct occlusal reshaping influenced this sub-category score. In contrast, Ortorp et al.[16] reported excellent anatomical form for each of the 25 single crowns in their study (11% of the original group) after three years.

Regarding the scores related to the biological properties of the crowns, 57 to 58% of the crowns had a sufficient or satisfactory periodontal response and a similar response regarding the adjacent mucosa (as compared to adjacent, unrestored teeth), which is in accord with the results of prior reports.[5,12,16] In previous investigations, the fit of the prosthetic framework was only rated as sufficient, and further improvements in marginal accuracy were deemed necessary.[7,15] Sailer et al.[7] stated that the lack of marginal accuracy explained the secondary caries that they observed. In our patients, no secondary caries were found; however, marginal accuracy also influences the mucosal response and thus may explain the current findings. This result partially contrasts with data reported by Vult von Steyern et al.[11] and Çehreli et al.[8] that demonstrated excellent marginal integrity in 80% of the crowns after a one- or two-year follow-up period.

The different scores that were obtained for marginal adaptation and periodontal response may be explained by the technical procedure itself, as several patients may have experienced invasion of the biological dental/mucosal width. After analyzing these results, the procedure was modified, and we expect that patients treated with the new, modified protocol will experience improved periodontal responses. Furthermore, customized oral hygiene maintenance protocols could be developed with the dental hygienist.

The lack of secondary caries in our patients was in contrast with previous studies.[5,7] Indeed, Hickel et al.[22] suggested that some clinical studies may have overstated the incidence of secondary caries. In fact, the diagnosis of recurrent caries can be made from the clinical point of view only, and the marginal discoloration that is often considered a sign of caries may instead represent a stained restoration margin. Unfortunately, only histological assessments can confirm this clinical diagnosis.

Overall, the cumulative three-year prosthetic survival rate observed in this study is in agreement with the literature[5,7,12] and is even greater than that reported from investigations where only tooth-supported single crowns were examined.[15,16] No differences were observed for either

single or multiple tooth- or implant-supported crowns. As the published literature on zirconia-core crowns for implants is limited, further investigations with more extensive follow-up periods are necessary.

In particular, due to the problem of fatigue fractures with all-ceramic prostheses,[1,3,13,14,17] a longer observation period is necessary.[19] This is especially warranted for rehabilitations in young patients who likely exert greater bite forces on their prostheses.

In conclusion, zirconia-core crowns appear to be a good clinical solution for both single- and multiple-unit prostheses, as they were shown to exhibit favorable aesthetic and functional properties. The marginal fit of these prostheses should be improved, as should the teamwork with the dental hygienist. Overall patient satisfaction was good, and the percentage of failures was limited in this clinical follow-up study. Undoubtedly, further longitudinal analyses are necessary, and the clinical performance of prosthetic reconstructions should be assessed five years after their placement.[19]

AUTHOR CONTRIBUTIONS

Tartaglia GM was responsible for the concept, design, execution, and interpretation of the study. Sidoti E was responsible for the bibliographic review, execution, and interpretation of the study. Sforza C was responsible for the concept, design, statistical analysis, and interpretation of the study.

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