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Zirconia single crowns and multiple-unit FDPs—An up to 8 -year retrospective clinical study

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ABSTRACT

Objective: The aim of this retrospective clinical study was to evaluate the survival and the occurrence of technical and biological complications of zirconia crowns and fixed dental prostheses made in the student clinic of Turku University, Finland, between April 2009 and September 2017.

Materials and methods: Twenty-seven patients (19 female, 8 male), with zirconia crowns or FDPs, participated in the follow-up investigation. The mean age of patients was 64.6 years. Of the 40 restorations, 17 were single crowns and 23 FDPs. Twenty-seven restorations were anterior and 13 posterior. Restorations were investigated according to modified USPHS criteria.

Results: The survival rate of zirconia restorations after 2–8 years (average 5.7 years) of clinical use was 95%. Survival rate of single crowns was 94.2% and of FDPs 95.7%, respectively. The overall complication rate was 26% for FDPs and 5.8% for crowns. One posterior crown was lost due to a vertical root fracture and one FDP showed a framework fracture. Veneering ceramic fractures were detected in 12% of all cases (0% for crowns and 22% for FDPs). Bleeding on probing was present in 38.1% of restored teeth and 13.9% of control teeth. Embrasure space was insufficient in 52% of zirconia FDPs and 81% of these restorations showed elevated BOP values.

Conclusions: Zirconia crowns and FDPs survived well in this retrospective follow-up study. Chipping of veneering ceramic and bleeding on probing were the most common complications. Thick connector areas made according to material demands resulted in insufficient embrasure spaces and inflammation of marginal gingiva.

1. Introduction

Despite the popularity of dental implant reconstructions, tooth-supported fixed dental prostheses (FDPs) are still a practical treatment option for replacing missing teeth, especially when the patients' remaining teeth would require a more complex restoration or if the conditions are not suitable for implant treatment. Tooth-supported metal-ceramic restorations have shown to be successful in long-term clinical follow-ups [1–3] and have been considered as a golden standard for FDPs. However, the demand for metal free constructions has led to significant development of all-ceramic materials that can nowadays be considered a suitable alternative to metal-ceramic restorations.

Partially yttria stabilized zirconium dioxide, zirconia, has been used as a framework material for single crowns and multiple-unit FDPs. The minimum thickness of the framework is defined by the manufacturer of each zirconia material, but material thicknesses below 0.5 mm have shown to be prone to framework fractures [4,5]. The framework can be fabricated with CAD/CAM techniques either from pre- or fully sintered zirconia and the veneering porcelain can be layered manually or by pressing or milling with CAD/CAM methods [6–8]. According to a systematic review article, the 5-year survival rate for tooth-supported zirconia FDPs is 90.4% [2]. Recently also monolithic zirconia FDPs have been introduced, but limited information is available about their clinical outcome [9–11].

As a restorative material, zirconia has esthetic, biocompatible and mechanical properties that are favorable, especially for multi-unit FDPs

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[12–14]. Although a randomized controlled study found no difference in patient satisfaction and oral health-related quality of life between the patients who received metal-ceramic FDPs compared to patients who received all-ceramic FDP [15].

In previous studies, the technical and biological complications seen with zirconia single crowns and FDPs are framework fractures, chipping of the veneering ceramic, secondary caries, loss of vitality of the abutment tooth, marginal discoloration and loss of retention [1,2,16,17]. Compared to other dental materials, the most common clinical problem with zirconia FDPs appears to be the chipping and fractures of the veneering ceramic [2], varying between 15–32 % during 5–10 years of follow-up time [11,18–20]. In the study of Teichmann and co-workers the chippings were seen frequently after the 8-year recall [18]. Previous studies have shown that the anatomical shape of the zirconia framework prevents chipping up to a certain level [21–23]. Matching the thermal expansion coefficients between zirconia and the veneering ceramic and slow cooling during the porcelain firing procedure, could also reduce the chipping rate [6].

More information about clinical outcomes of zirconia FDPs is still needed, especially when some of the existing studies are about the early-stage CAD/CAM procedures [16,20] and by far there is more knowledge on how to better avoid material related problems like porcelain chipping. The aim of this retrospective study was to evaluate the survival of tooth-supported single crowns and multi-unit zirconia FDPs, and the outcomes of technical and biological complications after 2–8 years of clinical service. The study hypothesis was that the zirconia crowns and FDPs have high survival rates, but some technical and biological complications will be seen.

2. Materials and methods

2.1. Study population

This retrospective clinical study was conducted in the Institute of Dentistry, University of Turku, Finland and in the student clinic of the Turku City Welfare division. The study was conducted as a registry study with no interventions. Ethical evaluation was therefore not required according to Finnish legislation.

Undergraduate dental students perform prosthodontic treatment on patients during their clinical training under supervision of prosthodontic specialists. Information on zirconia single crowns and FDPs was collected from the patient registry of the Turku city student clinic. Altogether 35 patients had received zirconia single crowns and multiple-unit FDPs between 04/2009 and 9/2017. Patients were contacted and 27 out of them (19 female, 8 male patients) were able to participate in a follow-up investigation. The mean age of patients was 64.6 years. These patients had received altogether 40 restorations, 17 single crowns and 23 FDPs. The majority of the restorations were maxillary anterior restorations. Distribution of these restorations is shown in Table 1.

2.2. Clinical and technical procedures

The abutment teeth were prepared according to general guidelines of tooth preparations for zirconia restorations. Impressions were taken using A-silicon or polyether impression materials (Express, 3 M ESPE; Affinis, Coltene Whaledent; Impregum Penta, 3 M ESPE). Provisional restorations were made with temporary composite materials with a chair-side technique and cemented using temporary luting agents (Temp Bond NE, Kerr and TempoSil, Coltene Whaledent).

Table 1
Type and distribution of zirconia restorations in the study population as retrieved from patient records.

	All restorations	Single crowns	FDP's	Number of units	
Patients	**27**				
Restorations	**40**	**17**	**23**	3-unit	9
Anterior	26	14	12	4-unit	9
Posterior	14	3	11	5-unit	1
Maxillary	39	17	22	6-unit	3
Mandibular	1		1	7-unit	1

Fig. 1. Clinical photograph of a maxillary posterior zirconia FDP replacing a second premolar. The clinical service time of the restoration is 7.5 years, and no technical complications are observed.

The technical procedures were done in three different dental laboratories. Eight restorations manufactured in 2009 were made using a copy-milling technique (ZirkonZahn GmbH, Sand in Taufers, Italy) from ICE Zirkon (ZirkonZahn) with Vita VM9 (Vita Zahnfabrik, Bad Säckingen, Germany) or GC Initial (GC Europe, Leuve, Belgium) as veneering porcelain. All subsequent restorations were made using CAD/CAM technology. Five of the CAD/CAM restorations were made from Metoxit Zirconia (Metoxit AG, Thayngen, Switzerland) and veneered with GC Initial (GC Europe, Leuve, Belgium). The majority of the CAD/CAM frameworks (n = 27) were milled with the PlanEasyMill system from Dental Direkt Zirconia (Dental Direkt GmbH, Spenge, Germany) and Vita VM9 was used as veneering material. Crowns and FDPs were fully veneered with veneering porcelain. A maxillary three-unit fully veneered FDP is seen in Fig. 1.

Single crowns were luted with either self-etching dual-cured resin cement (n = 11) (Relyx Unicem, 3 M ESPE), or dual-cured resin cement based on separate dentin bonding (n = 6) (Variolink II, Ivoclar Vivadent). The FDPs were luted with either a self-etching dual-cured resin cement (n = 16) (Relyx Unicem), with dual cured resin cement based on a self-etching bonding agent (n = 2) (Panavia, Kuraray) or zinc-phosphate cement (n = 3) (Phosphate cement, Heraeus Kulzer, Germany). Luting procedures were done according to manufacturers' recommendations. The operators had not been able to detach two FDPs with multiple abutments after a try-in period and they were still luted with temporary cement at the time of follow-up examination.

2.3. Clinical follow-up examination

During the follow-up examination, the patients were interviewed and a clinical examination was performed according to study protocol. Two authors (JT and JH) performed the examinations. Examiners were calibrated by both examiners performing evaluation on two patients. The clinical findings were compared and discussed. Failure was defined as a restoration having been removed or being in need of removal on a follow-up visit. Complication was defined as an event affecting function or esthetics. Restorations were investigated according to modified USPHS criteria [24]. Evaluation criteria are described in Table 2. Plaque index [25] and bleeding on probing (BOP) were recorded and probing pocket depth measured at four sites on abutment and control teeth on the contralateral side. The criteria for plaque index scores according to Silness and Löe were: 0 – no plaque; 1 – a film of plaque adhering to the tooth and free gingival margin detected with a probe; 2 – moderate accumulation of soft deposits on the tooth and gingival margin seen with the naked eye; 3 – abundance of soft matter on the

Table 2
Overview of the modified USPHS evaluation criteria used.

USPHS	Alpha (A)	Bravo (B)	Charlie (C)	Delta (D)
Patient satisfaction	Satisfied, no complaints	Criticism concerning esthetics, oral comfort, etc, transient symptoms	Unsatisfied, symptomatic but bearable	Very unsatisfied, unbearable symptoms
Marginal adaptation	No probe catch	Slight probe catch but no gap	Gap with some dentin or cement exposure	Renewal of restoration required
Veneering fracture	No fracture	Chipping but polishing is possible	Chipping down to the framework	Renewal of restoration required
Framework fracture	No fracture	–	–	Framework fracture
Retention	No loss of retention	–	Loss of retention at both/all abutments, recementation possible	Loss of retention at one/some abutment(s), recementation not possible
Anatomical form	Ideal anatomical shape	Slightly over or undercontoured	Highly over or undercontoured	Renewal of restoration required
Occlusal wear	No occlusal wear on restoration or antagonist teeth	Occlusal wear on restoration or antagonist teeth < 2mm	Occlusal wear on restoration or antagonist teeth > 2mm	New restoration needed
Color	Matches adjacent teeth	Slight mismatch in color or translucency	Gross mismatch in color or translucency	–
Secondary caries	No caries at crown margins	Secondary caries at crown margins, restorable	Caries requiring renewal of restoration	–

Table 3
Embrasure contour index (Wood et al. 1996).

Score	Criteria
0	A large gingival brush or periodontal aid easily passes embrasure or embrasure is visibly open.
1	Floss or small aid easily passes embrasure.
2	Space is limited but floss or periodontal probe passes embrasure.
3	Space is filled; floss or probing is not possible.

tooth and gingival margin. For plaque index, measurement was made at four locations (mesial, buccal, distal and palatal/lingual) and a mean plaque index was then determined as an average of the four readings. Bleeding on probing percentage was calculated for each abutment and control tooth individually, where each site accounted for 25% of the overall value. Bleeding at all four sites resulted in a 100% BOP score. In case of FDPs, measurements of all abutments were averaged. The tooth situated contralateral to the study tooth served as a control. In case it was missing or included as a study tooth, the neighboring contralateral tooth with similar morphology was used. A third option was to use the corresponding tooth in the opposing jaw. To evaluate the size and cleansability of embrasure spaces of the zirconia FDPs, embrasure contour index (ECI) was measured [26]. The height and width of the connector areas were also measured clinically, and the area of the connector was calculated. Table 3 describes the embrasure contour index.

Assessment of parafunctional oral habits was done according to the international consensus as proprosed by Lobbezoo et al. [27]. Based on anamnestic data and clinical findings, the subjects were graded as ‘non-bruxers’ (n = 16), ‘possible’ (n = 6) or ‘probable’ bruxers (n = 5). In the absence of sleep polygraphic recordings, the grading ‘definite bruxer’ could not be used.

Intraoral radiographs of the restored area were taken at the follow-up visit, in case no radiographs of the area in question had been taken during the follow-up period. Radiographs were used to evaluate the periapical status of abutment teeth and possible luting agent overhangs.

2.4. Statistical analysis

The distributions of study variables were studied and described. Differences in USPHS ratings between single crowns and fixed dental prostheses (FDPs) were evaluated using crosstabulations and the χ^2 test, and in case the assumptions for the χ^2 test were violated, the likelihood ratio (LR) test was used. Statistical analyses were performed using SPSS 24.

3. Results

The mean age of all restorations was 5.7 years, ranging from 1.8 to 8.4 years. The mean age of single crowns was 6.5 years and FDPs 5.0 years respectively. At the follow-up examination, 39 restorations out of 40 were still in function. One posterior single crown was lost during the observation period, due to a vertical root fracture of the endodontically treated abutment tooth. One FDP showed a framework fracture that was found at the follow-up examination. The survival rate of zirconia restorations after 2 to 8 years (average 5.7 years) of clinical use was 95%. The survival rate for single crowns was 94.2% and for FDPs 95.7%. The calculated mean survival time of all zirconia restorations was 8 years (crowns 8.02 and FDPs 7.98 y). An overview of the rating according to USPHS criteria is shown in Table 4. Table 5 summarizes all observed complications.

3.1. Technical outcomes

Veneering ceramic fractures were the most common failure type observed and were detected in 12% of all cases (0% for crowns and 22%

Table 4
Number of different USPHS ratings for all restorations, and single crowns and fixed dental prostheses (FDPs) separately. P-value indicates the difference in the proportion of A scores between groups (χ^2 and LR tests).

		All restorations n = 39	Single crowns n = 16	FDP's n = 23	p
Marginal adaptation	A	10	7	3	0.030
	B	26	9	17	
	C	3	0	3	
Veneering fracture	A	33	16	17	0.027
	B	5	0	5	
	C	1	0	1	
Framework fracture	A	38	16	22	ns
	D	1	0	1	
Occlusal wear	A	32	12	20	ns
	B	6	4	2	
	C	1	0	1	
Color	A	10	0	10	0.002
	B	29	16	13	
Sedondary caries	A	37	16	21	ns
	B	1	0	1	
	C	1	0	1	

Table 5
Overview of all complications (%).

		All	Crowns	FDP's
Technical	Fracture of framework	3	0	4
	Chipping of veneering	16	0	26
Biological	Bleeding on probing	38	30	44
	Probing pocket depth > 5 mm	23	12	22
	Secondary caries	5	0	9
	Fracture of abutment tooth		6	0

Fig. 2. Clinical photograph of a maxillary posterior FDP replacing a second premolar, with a clinical service time of 5.3 years. Several porcelain chippings can be seen on the occlusal surface of the restoration.

for FDPs). When veneering fractures were included as failures, the mean survival time for FDPs was 6.98 years. The complication rate was 26% for FDPs and 5.8% for crowns. A maxillary posterior FDP with occlusal veneering ceramic chippings is seen in Fig. 2.

The fractured FDP restoration was a maxillary anterior six-unit restoration with no pontics. The patient with the fractured FDP framework was graded a probable bruxer. Six restorations (FDPs) in five patients showed chipping of the veneering porcelain. Three of the five patients showing chippings in their FDPs were classified as possible bruxers. None of them used a night guard at the time of examination. The majority of restorations (92%) occluded against an intact or restored (composite or amalgam) natural tooth, two maxillary anterior crowns were opposed with a removable partial denture and one posterior FDP had a metal-ceramic FDP as an antagonist. Wear in the anterior region of dentition was detected in 30% of patients and generalized wear in 11% of patients. Veneering ceramic fractures could mostly be smoothed out and polished at follow-up visit.

A slight marginal discrepancy (slight probe catch, but no gap, USPHS rating B) was found in 9 single crowns (52%) and in 17 FDPs (74%). Marginal gap with some dentin or cement exposure (USPHS rating C) was seen in 3 FDPs (13%). Subsequent overall marginal degradation of FDPs was 87%.

3.2. Biological outcomes

Secondary caries was seen in two abutment teeth of FDPs. One of them was still restorable (USPHS rating B) while the other required renewal of the restoration (USHPS rating C). The FDP with rating C was temporarily cemented (Temp Bond, Kerr). More bleeding on probing (BOP) was detected at the study teeth (38.1%) compared to control sites (13.9%) ($p = 0.001$). Moreover, abutment teeth for FDPs showed a slightly higher mean BOP score (44%) than abutment teeth for crowns (30%) ($p = 0.125$). Mean plaque index scores were 0.2 for abutment teeth and 0.6 for control teeth ($p < 0.001$). Twenty-three percent (9/39) of teeth with zirconia single crowns or FDPs had probing pocket depth (PPD) ≥ 5 mm, whereas for control teeth PPD ≥ 5 mm was detected for only 5% (2/39).

The average ECI score was 1.6 for all FDPs studied. Of all FDP embrasures measured, 10% scored 3, 42% scored 2, 40% scored 1 and 8% scored 0. Average measured connector area was 17.21 mm^2, ranging from 7.39 to 30.16 mm^2. There was an association between the BOP values and ECI. Marginal gingiva adjacent to embrasures with ECI scores 2 or 3 (space limited or closed) showed bleeding on probing in 81% of cases. With ECI scores 0 or 1 (sufficient cleaning space) bleeding was present in 40% of cases and the difference was found statistically significant ($p = 0.003$). Figs 3a and b illustrate a case with a closed embrasure space (ECI 3) and increased bleeding on probing.

3.3. Patient satisfaction

Patients were generally very satisfied with their restorations, 85% (n = 21) of patients scored an A for patient satisfaction. The complaints reported were mostly related to difficulties in cleaning the embrasure spaces of FDP restorations and subsequent pain and bleeding of gingival tissue. This could also be seen clinically and was often associated with small clinical crown height and large connector height of the FDPs.

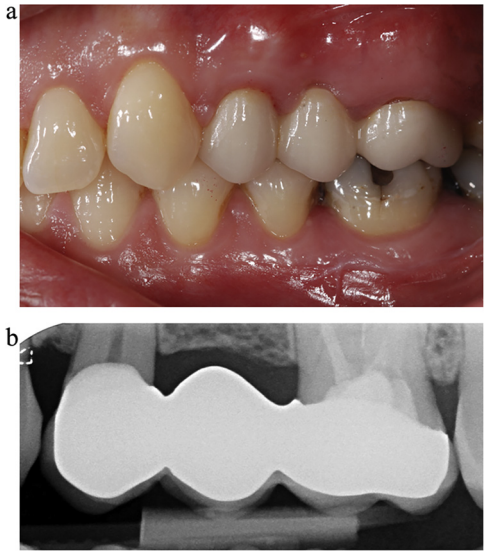

Fig. 3. Clinical photograph (a) and an intraoral radiograph (b) of a maxillary posterior FDP with insufficient embrasure spaces resulting in maintenance problems and an inflammation in the gingival tissues.

4. Discussion

This study was conducted in order to evaluate the survival and the outcome of technical and biological complications of tooth-supported single crowns and multi-unit zirconia FDPs after 2–8 years of clinical service. The study hypothesis was accepted since the 5.7-year survival of zirconia single crowns and FDPs was high (95%) and some technical and biological complications were seen, more with FDPs than with single crowns. Chipping of veneering porcelain was the most common technical complication and was seen in 26% of FDPs but not in single crowns. No loss of retention was seen in either crowns or FDPs.

The presence of parafunctional habits (bruxism), unpolished ceramic surface, ceramic restoration on antagonist tooth and absence of occlusal splint have been reported as possible risk factors for porcelain chipping [19]. In the present study four out of five patients showing chipping were graded as possible or probable bruxers and had signs of local anterior or generalized wear in their dentition. Moreover, none of them used an occlusal splint. Parafunctional oral habits may in part explain the observed chippings. Bruxers have been shown to have more technical complications in FDPs in general [28]. Also, some of the restorations in the present study were manufactured using early stage processing techniques and shortcomings in framework design are possible. The patients with parafunctional habits could not be excluded from this retrospective study beforehand.

Chippings of the veneering porcelain seems to be a common complication of zirconia FDPs [1,11,16,18–20]. It is seen in metal-ceramic FDPs as well [1,29], but the major fractures of the veneering porcelain have only been seen in zirconia FDPs [1]. In the present study no chippings in the single crowns were seen. This differs from the study of Koenig and colleagues where equal amounts of chippings were seen in zirconia single crowns and FDPs [19]. Two recent studies reported a chipping rate of 11.7–12.4% among zirconia single-crows [30,31], however the chippings were seen in the posterior crowns and the anterior crowns were intact. This is in accordance with the results of the present study as a majority of the crowns were situated in the anterior area and no single crowns on molars were present. In the present study, 4 out of 6 restorations with chipping had 4 or more units. In a previous study a clear correlation between the chipping and the length of the span of the FDPs was seen: 4- and 5-unit FDPs had a 4.9 times higher probability for chipping compared to 3-unit FDPs [20]. Additionally, it was shown that the risk for chipping was higher, the longer the clinical service time of FDP. Due to the retrospective nature of the present study, the age of FDPs at time of chipping could not be determined.

In general, less biological and technical complications were seen in zirconia single crowns than in FDPs during 2–8 years of clinical service in the present study. No loss of retention, veneer chippings or secondary caries was seen with crown restorations, but some marginal discrepancy with slight probe catch was seen in 52% of the single crowns. In the review article by Sailer and colleagues, it was concluded that due to higher rate of technical complications zirconia-based single crowns should not be considered as primary treatment option [17]. Based on the results of the present study, zirconia single crowns are surviving well, however the esthetic demands were not always reached. For the color appearance variable, zirconia FDP restorations scored an A rating more frequently than zirconia single crowns ($p = 0.002$). Most of the single crowns (14/17) in the present study were maxillary anterior crowns. The esthetic demands for this area are high and translucency of the restoration has a major effect on its appearance. In single crown restorations, matching the color to adjacent teeth is better accomplished with glass-ceramic restorations or with more recently introduced translucent zirconia materials since they have the optical properties closer to tooth compared to first-generation zirconia materials [32–34]. In the present study, the first-generation framework zirconia material was used, and this can give an opaque appearance even if the restoration is veneered with feldspathic porcelain.

In the study of Sax and colleagues, marginal discrepancy or degradation was seen in 90.7% of the zirconia FDPs with 10 years of follow-up time [20]. The authors discussed that this could be due to the inaccuracy of the early CAD/CAM procedures. In later studies the marginal discrepancy or degradation have also been seen but to a smaller extent [1,16]. In the present study the marginal discrepancy was larger with zirconia FDPs, where the majority of the restorations (17/23) received USHPS rating of B (slight probe catch with no gap) and 3/23 of the FDPs received rating of C (gap with some dentine or cement exposure). This could also be a result of processing methods, when possible inaccuracies in the processing phase can lead to a misfit on the marginal area.

Multiple studies have been conducted to define the best way to bond zirconia surfaces to resins [35]. The higher bond strength is reached when the surface is roughened with light air-borne particle abrasion, grain size 50 μm and pressure of 2.5 bar and an MDP-monomer is used with resin cement [36]. The zinc phosphate cement should not be recommended at all due to unfavorable properties such as brittleness and water-solvability [37]. In the study of Rinke and co-workers the zirconia FDPs showed increased rates for loss of retention and marginal secondary caries that could be due to semi-optimal fit of the restorations (early CAD/CAM system) and using the zinc phosphate cement [16]. In the present study, five different cements were used and none of the frameworks were treated with air-borne particle abrasion. However, no loss of retention was seen, and the retention was based on macromechanical retention of the abutment teeth. The FDP with detrimental carious lesion was cemented with temporary cement. The secondary caries is likely to have formed due to loss of highly water-soluble temporary cement. It should be advised to make several attempts to remove a temporarily cemented FDP in order to avoid future complications.

Plaque accumulation was low in general for both the abutment teeth and control teeth. Average plaque index scores were below 1, meaning that for most patients, plaque accumulation on the studied teeth could not be detected with the naked eye. Still, statistically significantly less plaque was detected on zirconia restorations compared to control teeth. This may be explained by the previous observation that ceramic materials have been found to retain less plaque than other restorative materials [13,38]. Also, plaque on ceramics was found to have reduced vitality compared to other materials [39].

Although plaque was detected only minimally, bleeding on probing was significantly increased among abutment teeth compared to control teeth. These findings are in line with previous literature. Some studies report bleeding on probing as a common biologic complication related to zirconia restorations [18,40]. In other studies, however, no elevated counts in the periodontal parameters have been seen [1,41]. The reason for mucosal irritation is however most likely more related to periodontal factors, the oral hygiene status of an individual patient or the marginal accuracy and anatomical form of the structure, rather that the restoration material itself. In the present study, the ECI index revealed insufficient embrasure spaces in 52% of FDP connector areas. Together with subgingival crown margins and over contouring of anatomic form, insufficient embrasure spaces clearly influenced the marginal gingival health. Increased probing pocket depth was also detected more often in abutment teeth compared to control teeth. However, some patients with increased PPD had not attended regular maintenance visits and some were smokers.

In this retrospective study the single crowns and FDPs with a zirconia framework showed good clinical performance. The fact that most of the restorations were placed in anterior maxilla, indicates that the choice of material was mainly based on cosmetic demands. Although less plaque was found on zirconia surfaces compared to control teeth, there was more bleeding on probing present on zirconia restorations. Thick connector areas made according to material demands, resulted in insufficient embrasure spaces and inflammation of marginal gingiva. This phenomenon was found particularly when the clinical crown height was small. In the future a randomized controlled clinical trial

could give more information on the exact time of the complications. Also, more recently introduced novel monolithic zirconia restorations should be evaluated, as the preliminary clinical results seem to be promising [9–11].

5. Conclusions

Zirconia is a suitable material for single crowns and FDPs. The survival rate is high, but technical and biological complications can be expected. Attention must be paid to the shape of the framework, especially on connector areas, in order to maintain gingival health.

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