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Three-unit posterior zirconia-ceramic fixed dental prostheses (FDPs) veneered with layered and milled (CAD-on) veneering ceramics: 1-year follow-up of a randomized controlled clinical trial

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Objective: The aim of this multicenter randomized controlled clinical trial was to test posterior zirconia-ceramic fixed dental prostheses (FDPs) veneered with a computer-aided design/computer-assisted manufacture (CAD/CAM) lithium disilicate veneering ceramic (CAD-on) and manually layered zirconia veneering ceramic with respect to survival of the FDPs, and technical and biologic outcomes. **Method and Materials:** Sixty patients in need of one posterior three-unit FDP were included. The zirconia frameworks were produced with a CAD/CAM system (Cerec inLab 3D/Cerec inEOS inLab). Thirty FDPs were veneered with a CAD/CAM lithium disilicate veneering ceramic (Cad-on) (test) and 30 were veneered with a layered zirconia veneering ceramic (control). For the clinical evaluation at baseline, 6, and 12 months, the United States Public Health Service (USPHS) criteria were used. The biologic outcome was judged by

comparing the plaque control record (PCR), bleeding on probing (BOP), and probing pocket depth (PPD). Data were statistically analyzed. **Results:** Fifty-six patients were examined at a mean follow-up of 13.9 months. At the 1-year follow-up the survival rate was 100% in the test and in the control group. No significant differences of the technical outcomes occurred. Major chipping occurred in the control group ($n = 3$) and predominantly minor chipping in the test group (minor $n = 2$, major $n = 1$). No biologic problems or differences were found. **Conclusions:** Both types of zirconia-ceramic FDPs exhibited very good clinical outcomes without differences between groups. Chipping occurred in both types of FDPs at small amounts, yet the extension of the chippings differed. The test FDPs predominantly exhibited minor chipping, the control FDPs major chipping. (*Quintessence Int* 2015;46:871–880; doi: 10.3290/j.qi.a34701)

Key words: CAD/CAM, CAD-on, fixed dental prosthesis, lithium disilicate, zirconia

Today, all-ceramic reconstructions are being increasingly used due to their high esthetics and good biocompatibility. Various all-ceramic systems for the fabrication of single crowns and multiple-unit fixed dental

prostheses (FDPs) have been developed over the years. One specific focus was the development of ceramics with high stability that could be used as framework material for FDPs in posterior regions.¹ One of those

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ceramics was the high-strength ceramic yttrium-stabilized tetragonal zirconia polycrystals (Y-TZP). This ceramic was shown to have excellent mechanical properties² and performed very well as framework material in a high number of clinical studies.^{1,3,4} Another more recent development for posterior all-ceramic FDPs was a lithium-disilicate-reinforced glass-ceramic (e.max CAD) with high flexural strength of up to 400 MPa. The higher mechanical stability of lithium-disilicate glass-ceramic compared to, for example, leucite-reinforced glass-ceramic was the result of an improved design of the microstructure.

Both zirconia and lithium-disilicate glass-ceramic have benefits and limitations. Zirconia-based reconstructions on one hand exhibited low rates of framework fractures, happening at incidences of 0% to 1%.^{5,6} On the other hand the zirconia-based reconstructions suffered from high rates of chipping of the veneering ceramic of up to 54%.^{5,7-9}

In contrast, the lithium-disilicate-based reconstructions had a low incidence of chipping, but catastrophic fracture was reported for 2.1% of the single crowns¹⁰ and around 6%¹⁰⁻¹⁶ or even more¹⁷ of the multiple-unit FDPs. Compared to conventional layered ceramic, lithium-disilicate glass-ceramics exhibit higher strength, while still maintaining a favorable translucency and shade variety for a good esthetic result. In addition, the lithium-disilicate ceramic is available as industrialized prefabricated ingots that are processed by means of computer-aided design/computer-assisted manufacture (CAD/CAM) technology. These ingots are dense and homogenous and not porous as manually layered ceramics can be. Hence, it might be speculated that CAD/CAM lithium disilicate ceramic covers may exhibit better clinical outcomes when used for the veneering of zirconia as manually layered veneering ceramics.

The reasons for the high rates of chipping of the zirconia veneering ceramics are still not fully understood. A number of different factors have been identified in recent years. One of the main factors was the veneering procedure itself, ie the baking and cooling temperatures as well as the holding times.^{18,19} Despite the adaptation of the veneering ceramic manufactur-

ers' recommendations to the needs of zirconia, the incidence of chipping has not been eliminated yet.⁵ For this reason, new veneering techniques like pressed veneering ceramic on a zirconia framework²⁰ or milled veneering ceramics (eg, CAD-on) have recently been introduced.

The new technique of milled veneering ceramic combines CAD/CAM fabrication of a zirconia framework with CAD/CAM fabrication of a monolithic veneering coating out of a lithium-disilicate glass-ceramic (CAD-on). This specific technique takes advantage of the general benefits of the CAD/CAM technology: high strength materials, more efficient production, and industrial quality standards.

The first in-vitro studies display a higher fracture resistance of zirconia crowns veneered with this CAD/CAM veneering ceramic technique (CAD-on) than of crowns veneered with the layering technique.²¹ However, very scarce information on the clinical outcomes of this new type of CAD/CAM veneering ceramic compared to the manually layered veneering ceramic is available today.

Therefore, the aim of this randomized controlled clinical trial was to test posterior zirconia-ceramic FDPs veneered with a CAD/CAM veneering ceramic (CAD-on) and manually layered zirconia-ceramic FDPs with respect to survival of the FDPs, and technical and biologic outcomes. The outcome of the two types of veneering ceramics was analyzed with special emphasis.

The null-hypothesis was that zirconia-ceramic FDPs veneered with the CAD/CAM veneering ceramic (CAD-on) technique would exhibit similar clinical outcomes to the manually layered zirconia-ceramic FDPs.

METHOD AND MATERIALS

Study design and patient selection

In this multicenter randomized controlled clinical trial two clinics at the Center of Dental Medicine, University of Zurich, participated: Clinic 1 (KBTM) and Clinic 2 (PPK).



Table 1 Overview of the number of test and control FDPs, the respective arches, and the types of teeth replaced by means of the FDPs		
	Test group (CAD-on)	Control group (layered)
Number of FDPs	30	30
Pontic sites- maxilla	6PM; 8M	9PM; 10M
Pontic sites- mandible	2PM; 14M	3PM; 8M

M, molar; PM, premolar.

Both clinics followed the same study protocol. This protocol was approved by the local Ethical Committee of the University of Zurich (Ref. No. EK StV 08/13). Patients willing to participate were thoroughly informed about the procedures and materials, and signed an informed consent form.

The general inclusion criteria for the patients were:

- aged between 18 and 70 years
- good general and periodontal health
- no allergies to any of the used materials
- no obvious signs for bruxism or clenching
- no pregnancy
- compliance to the follow-up visits expected to be good

The site-specific inclusion criteria were:

- presence of a single tooth gap in the maxillary or mandibular posterior region with:
 - one missing 2nd premolar or 1st/ 2nd molar
 - teeth adjacent to the gap in need of a reconstruction (abutment teeth)
 - abutment teeth either vital, or with a lege artis endodontic treatment (absence of periapical lesion, apparent periodontal space)

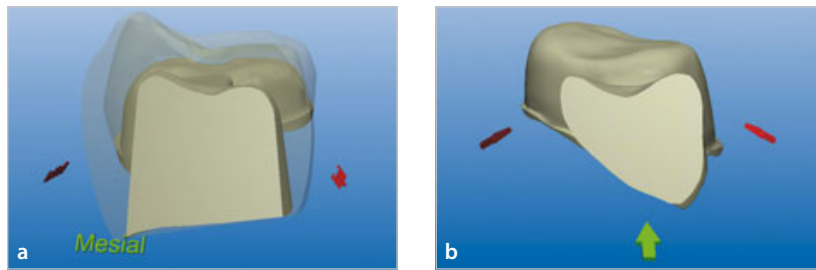
Sixty patients matching the above-mentioned criteria were included; out of those 30 were treated at Clinic 1 and 30 at Clinic 2. The present study population at baseline consisted of 60 patients with 60 three-unit zirconia-based FDPs located in the posterior maxillary or mandibular region. The mean age of the patients at baseline was 52 years (range from 25 to 70 years).

At each clinic the patients were computer-randomly assigned to one of the tested zirconia veneering procedures. The patients receiving a zirconia-ceramic FDP with a CAD/CAM-fabricated veneering ceramic (CAD-on) were assigned to the test group. The patients receiving a zirconia-ceramic FDP with layered veneering ceramic served as control (Table 1).

CLINICAL PROCEDURES

Prior to the restorative treatment the same oral hygiene status was established in all patients with aid of dental hygienic pretreatment. The abutment teeth were prepared according to the guidelines for all-ceramic reconstructions.^{13,22} The preparation design encompassed 1 mm of marginal shoulder depth, 1.5 mm axial reduction, and 1.5 to 2 mm occlusal reduction. The taper of the axial walls was 6 to 15 degrees. The line angles and edges were thoroughly rounded. After the preparation, a desensitizer (Gluma, Heraeus Kulzer) was applied to vital abutment teeth.

Impressions of the prepared arches were made using either an A-silicone impression material (President, Coltène; Honigum, DMG) or a polyether impression material (Permadyne, Garant/Penta, 3M Espe). The impressions of the opposing arches were made with alginate. Bite registration was performed with a silicone bite registration material (Preciform, N HardBite, Merz Dental). Provisional restorations were fabricated using a composite material (Pro Temp, 3M Espe) and were cemented with eugenol-free temporary cement (Freegenol, GC).



Figs 1a and 1b These figures show the difference in the framework design most specifically occurring in the pontic area. In the Cad-On group, no undercut can be designed.

Framework fabrication

One trained and calibrated dental technician manufactured all FDPs in this study.

The impressions were poured with stone (Fujirock, GC). The casts were optically scanned using a CAD/CAM system (Cerec inEOS inLab MC XL, Sirona) and the frameworks were virtually designed (Cerec inLab 3D software V3.85 and V3.88, Sirona). The design of the framework shape and dimensions for the conventional and the CAD-on veneering ceramics was pre-set in the software of the CAD/CAM system. Different framework shapes were needed for the two types of veneering procedures. The differences are highlighted in Fig 1.

The minimal framework dimensions were 0.5 mm of thickness in the axial region and 0.7 mm thickness in the occlusal region, leaving a minimal space of 2 mm for the veneering ceramics. The connectors were designed with a minimal cross-section of 6 mm². The shape suggested by the software was slightly modified by the trained dental technician following the individual needs of the clinical cases.

The zirconia frameworks were milled out of Y-TZP partially sintered zirconia blanks (IPS e.max ZirCAD, Ivoclar Vivadent) using the milling unit of the respective CAD/CAM system (Cerec inLab). After the milling the frameworks were sintered to full density in a high-temperature furnace (Programat S1, Ivoclar Vivadent). Shading of the frameworks with coloring liquids (IPS e.max ZirCAD Colouring Liquids) was performed prior to the sintering.

Before the veneering procedures, all frameworks were clinically checked with respect to fit and anatomical support of the veneering ceramics.

Veneering procedures

Test group: CAD/CAM veneering ceramic (Cad-on)

The CAD/CAM veneering ceramic covers (CAD-on) were virtually designed by means of the same software that was used for the design of the frameworks (Sirona inLab 3D software V3.85 and V3.88).

The veneering ceramic covers were milled out of pre-sintered lithium-disilicate ceramic ingots (IPS e.max CAD, Ivoclar Vivadent). The appropriate choice of ingot color was made by the dental technician according to the individual needs in each patient situation. Prior to final crystallization firing, the fit of the CAD/CAM (CAD-on) covers was adjusted to the frameworks in the internal and marginal regions with diamond burs or diamond-coated rubber wheels. The covers and the frameworks were fused during the final sintering process of the CAD/CAM (CAD-on) veneering ceramic. For this, a liquid fusion glass-ceramic (IPS e.max CAD Crystall/Connect) was applied to the internal side of the CAD/CAM (CAD-on) ceramic covers and the covers were positioned onto the frameworks. Even dispersion of the fusion ceramic was aimed for by placing the FDPs onto a vibrating unit (Ivomix, Ivoclar Vivadent). The fusion ceramic was sintered during the crystallization firing and the glaze firing of the lithium-disilicate ceramic (840°C), which were performed strictly adhering to the manufacturer's guidelines in a conventional ceramic furnace (Programat P500, Ivoclar Vivadent). The esthetic outcome of the monolithic veneering ceramic was improved with staining colors (IPS e.max CAD Crystall/Stains, Ivoclar Vivadent).

In some cases the basal part of the pontic regions had to be manually adjusted to the anatomical situation of the patients (IPS e.max CAD Crystall/Add-On, Ivoclar Vivadent).

Control group: layered veneering ceramic

In this group, the veneering ceramic (IPS e.max Ceram, Ivoclar Vivadent) was applied by manually layering veneering ceramic onto the framework following the manufacturer's guidelines. For this, the frameworks were coated with a liner (IPS e.max Ceram ZirLiner, Ivoclar Vivadent) and baked at 750°C to achieve a better bond between the framework and the veneering ceramic. This was followed by the application and baking of wash firing and two or three layers of veneering ceramic at a temperature of 750°C. For the firing the conventional ceramic furnace (Programat 500, Ivoclar Vivadent) was again used.

The finishing of the veneering ceramic shape was performed with diamond burs. The thickness of the veneering ceramic was checked using a silicone key of the diagnostic wax-up. This wax-up was made at the beginning of the treatment to define the desired outline of the reconstruction (Optosil, Heraeus Kulzer). The esthetic outcome was improved with painting colors and a glazing ceramic (IPS e.max Ceram Glaze Paste, Ivoclar Vivadent; 725°C).

Cementation

Prior to the cementation the FDPs were clinically checked. The marginal fit, the occlusal and functional contacts, the interproximal contacts, and the esthetic outcomes were judged. For the cementation, the internal surfaces of the FDPs were cleaned with alcohol. The abutment teeth were cleaned with fluoride-free pumice (Cleanic, Kerr).

All FDPs were cemented with the same resin cement (Multilink Automix, Ivoclar Vivadent) according to the manufacturer's instructions.

Baseline and follow-up examinations

After the cementation the FDPs were clinically and radiographically evaluated at baseline, 6 months, and 12 months. For the clinical evaluation, modified United States Public Health Service (USPHS) criteria were used.^{23,24}

The clinical examinations were performed by four calibrated examiners (two per clinic). According to the

protocol the same examinations were performed at baseline (ie, cementation), and at 6 and 12 months. Further follow-up examinations will take place once per year up to a follow-up period of 5 years.

The FDPs were examined with respect to their technical outcomes. For this, the integrity of the frameworks and the veneering ceramic was examined and further factors such as marginal adaptation, occlusal wear, and retention were integrated in the USPHS criteria (Table 2).

For the analysis of the biologic outcome the following parameters were assessed at test (abutment) and control teeth (analogous contralateral unrestored teeth):

- pocket probing depth (PPD), 4 sites per tooth
- plaque control record (PCR), 4 sites per tooth²⁵
- bleeding on probing (BOP), 4 sites per tooth.

Finally, an impression of the FDP and a replica of the FDPs were made at each follow-up visit.²⁶ For this the FDPs were thoroughly cleaned with alcohol without scratching the surface of the veneering ceramic with the instruments, and impressions were made using an A-silicone impression material (President, Coltène)²⁶. The impressions were poured with epoxy resin (EpoFix, Struers) in order to fabricate the replicas of the FDPs.

Statistical analysis

Linear mixed effects analysis was performed to investigate probing depth, and generalized linear mixed effects analyses for Poisson distributed data were applied for Plaque Index (PI) and BOP (statistical software R, R Foundation for Statistical Computing). Group (test or control, between subject), time-point (baseline or after 1 year, within subject), and tooth type (test or control tooth, within subject) were entered as fixed factors, and participants as a random factor into the models. *P* values were obtained by likelihood ratio tests.

The USPHS scores were analyzed using nonparametric Wilcoxon test to determine the effect of time-point. Group comparison for each time-point separately was performed using chi-square test. A *P* value < .05 was considered significant.

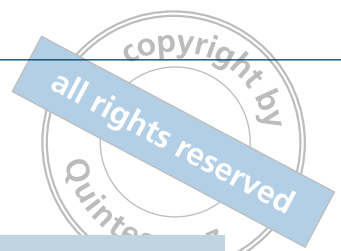


Table 2 USPHS criteria				
USPHS	Alpha (A)	Bravo (B)	Charlie (C)	Delta (D)
Patient satisfaction	Very satisfied, no complaints	Criticism of esthetics/chewing comfort, etc. Symptoms for a short time after treatment.	Dissatisfied, complaints permanent but tolerable	Completely dissatisfied, unbearable pain, reconstruction to be renewed
Marginal adaptation	Very good adaptation, dental probe does not stitch	Probe stitches but does not penetrate the margin, no marginal gap	Marginal gap exists, not polishable, exposed dentin or cement	Reconstruction to be renewed
Framework fracture	No fracture of framework			Fracture of framework, reconstruction to be renewed
Veneering of ceramic chipping/fracture	No chipping/fracture	Chipping, but polishable	Extended fracture of veneering ceramic up to the framework	Reconstruction to be renewed
Retention	No loss of retention		Loss of retention but reconstruction can be re-cemented	Loss of retention reconstruction cannot be re-cemented, reconstruction to be renewed
Anatomical shape	Ideal for the remaining dentition, suitable form	Slightly under- or over-contoured	Significant under- or over-contoured	Reconstruction to be renewed
Interproximal contact	Good interproximal contact	Weak interproximal contact	No interproximal contact but tolerable	Reconstruction to be renewed
Occlusal contacts	Normal occlusal contact, no balancing contact	Increased occlusal contact and/or balancing contact, can be adjusted	No occlusal contacts, or hyper-balancing contact	Occlusion/function inadequate, reconstruction to be renewed
Occlusal wear	No occlusal wear on reconstruction or on opposite teeth	Occlusal wear on reconstruction or on opposite teeth is < 2 mm	Occlusal wear on reconstruction or on opposite teeth is > 2 mm	Reconstruction to be renewed
Color	No difference in color and translucency between the FDP and dentition	Deviation between the FDP and dentition within an acceptable level	Deviation between the FDP and dentition beyond the acceptable level	FDP esthetically unacceptable, reconstruction to be renewed
Caries	No caries in the marginal area	Inactive caries not requiring treatment (caries sica/V defect)	Secondary caries need for treatment, treatment possible	Pronounced secondary caries requires renewing of the FDP
Radiograph	Cementation gap of the FDP on the radiograph	Cementation gap of the FDP clearly visible on the radiograph	Cementation gap of the FDP clearly indicated in the radiograph	Pronounced marginal gap, visible, peri-apical lesion, tooth fracture, renewing of FDP needed
Vitality/biology	Significantly positive (CO ₂); negative at existing root canal filling	Uncertain or delayed positive; no sensitivity on percussion, no whitening	Clearly negative, no root canal filling present or periapical lesion treatment needed	Abutment tooth to be extracted, removal of FDP needed

RESULTS

Fifty-six of the originally included 60 patients (33 female, 23 male, mean age 52 years) were examined at a mean follow-up of 13.9 months (standard deviation 3.2 months). Four patients were lost to follow-up out of different reasons. One patient unfortunately passed away and three could not be reached for the 1-year follow-up examination. Due to this, three test and one control FDP could not be examined.

No FDP was lost due to catastrophic fracture including the framework, or out of another reason during the

present follow-up period. Hence, the 1-year survival rate was 100% in the test and in the control group.

Furthermore, the test and control FDPs did not exhibit significant differences with respect to their technical outcomes as rated by the USPHS criteria ($P > .05$).

Chipping/fracture of the veneering ceramic occurred similarly in both groups; 11% of the test ($n = 3$) and 10.3% of the control FDPs ($n = 3$) exhibited veneering ceramic chipping or fracture at 1 year (Table 3). In addition the incidence of chipping significantly increased between baseline and 1-year follow up ($P = .01$). Patients were informed about the observed problems.

Table 3		USPHS-rating of the test group (TG) and control group (CG) FDPs				
		USPHS				Type of FDP
		Alpha (A)	Bravo (B)	Charlie (C)	Delta (D)	
Framework fracture	27					TG
	29					CG
Veneering ceramic chipping/ fracture	24	2	1			TG
	26	0	3			CG
Occlusal wear	27	10				TG
	23	6				CG
Marginal adaptation	15	12				TG
	15	14				CG
Anatomical form	22	5				TG
	28	1				CG

In the test group two FDPs had minor superficial chipping of the veneering ceramic rated B, and one FDP had a major fracture of the veneering ceramic rated C (Table 3).

This latter case, unfortunately, could not be evaluated to full detail due to the fact that the patient did not inform the investigators about the problem at the time when it occurred. Instead, he could not remember how it happened and had already gone to have it repaired by his private dentist. Interestingly, this major chipping had happened in the region where the baseline radiographic examination of the respective FDP had displayed radiolucency between the veneering coating and the framework. Maladaptation of the CAD/CAM veneering coating and adjustment to the framework might be a reason for this gap and might be speculated as the origin of failure. Unfortunately, further observation of this particular FDP will not be possible since this patient informed the study investigators that he would emigrate to Canada after the 1-year follow-up visit.

At the two test FDPs that had minor chippings, in addition fracture lines within the veneering ceramic, along the distal connectors were observed (Fig 2). The



Fig 2 Clinical image displaying a test FDP with a minor chipping of the veneering ceramic, rated Bravo by means of the USHPS criteria.



Fig 3 Clinical image of a control FDP exhibiting a veneering ceramic fracture, rated Charlie by means of the USHPS criteria.

fractured areas were thoroughly polished using ceramic polishers (OptraFine, Ivoclar Vivadent).

In contrast to the minor problems in the test group, all observed chippings ($n = 3$) in the control group were major fractures of the veneering ceramic rated C (USPHS) (Fig 3). Furthermore, in both groups a significant increase in occlusal wear of the veneering ceramic was observed when baseline and the 1-year recall were compared ($P = .003$). No further technical complications were observed in both groups.

Few biologic differences were found when test and control group were compared. At baseline and at the 1-year follow-up, the abutment and corresponding control teeth in the FDP test group exhibited significantly lower PPD values than the abutment and control teeth in the FDP control group ($P = .02$). No significant differences of the PI and BOP were found between the test and control groups ($P > .1$) (Table 4). No secondary caries was found in the test or in the control group. One abutment tooth in the control group had to be endodontically treated during the first year. The radiographic examination of the test and control FDPs at baseline and the follow-up visits indicated no changes over time (Tables 3 and 4).



Table 4 Mean values and standard deviations of the biologic parameters at abutment teeth (test) and analogous contralateral untreated teeth (control) of both types of FDPs at 1 year

Teeth	Test FDPs		Control FDPs	
	Test	Control	Test	Control
PPD	1.5 ± 0.2	1.5 ± 0.3	1.6 ± 0.3	1.7 ± 0.3
PCR	0.2 ± 0.2	0.3 ± 0.2	0.1 ± 0.1	0.3 ± 0.1
BOP	0.2 ± 0.2	0.1 ± 0.1	0.2 ± 0.2	0.1 ± 0.2

BOP, bleeding on probing (mm); PCR, plaque control record; PPD, pocket probing depth.

DISCUSSION

The newly developed CAD/CAM (CAD-on) zirconia-ceramic FDPs exhibited good clinical outcomes at 1 year of follow-up similar to those of manually veneered zirconia-ceramic FDPs. No catastrophic fracture or other failure of a test or control FDP occurred, hence the 1-year survival rate was 100% in both groups.

The technical outcomes of the two types of zirconia-ceramic FDPs were similar. Chipping or fracture of the veneering ceramic was a technical complication found in both groups at the same amounts. However, the CAD/CAM (CAD-on) zirconia-ceramic FDPs predominantly exhibited minor superficial chipping, whereas at layered zirconia-ceramic FDPs pronounced fractures of the veneering ceramic were found. These differences were not of statistical significance, but the differences of the size of the ceramic chipping/fracture may have a clinical impact and need further observation. In addition, for both types of FDPs long-term increasing occlusal wear of the veneering ceramic was observed. No further technical problems occurred. The biologic integration of the new CAD/CAM (CAD-on) zirconia-ceramic FDPs was excellent. No differences in plaque and bleeding on probing indices were found between groups. The teeth in the test group in general exhibited lower PPDs than the teeth in the control group. In summary, for the present observation period the null-hypothesis of this study was accepted.

The very good present clinical survival rates of the tested zirconia-ceramic FDPs are in accordance with

the previously published literature on zirconia-ceramic FDPs.⁶ In general, very low or no fracture rates of zirconia frameworks were reported in the previous studies, and no fracture of a zirconia-ceramic FDP was observed in the present study. Furthermore, the biologic integration of both test and control FDPs was excellent in the present and previous studies.

The main issue of the zirconia-ceramic FDPs was chipping of the veneering ceramic.⁵ For this reason, numerous new types of veneering ceramics and veneering techniques have been developed for zirconia in recent years.²⁷ The rates for chipping, however, have not significantly been lowered.^{28,29}

A recently developed veneering technique for zirconia frameworks encompassed the combination of a CAD/CAM veneering coating milled out of a lithium-disilicate glass-ceramic ingot and zirconia framework. The general concept of this new development is the combination of a zirconia framework with a veneering cover milled out of an industrially prefabricated highly stable glass-ceramic ingot.²⁰

In comparison to conventional silica-based veneering ceramics, lithium-disilicate glass-ceramics exhibit higher fracture load and toughness.²⁰ In addition, the lithium disilicate reconstructions exhibited very low rates for chipping in recent clinical studies.³⁰

The present results support the assumption that this highly stable lithium-disilicate veneering coating would exhibit low rates of chipping when used as veneering ceramic for zirconia framework; however, this needs to be further specified after longer observa-

tion periods. One interesting observation in the present study was that the major fracture of the veneering ceramic found in one test FDPs occurred in the same region where previously a gap between the veneering ceramic coating and the framework was seen on the radiograph. It may be assumed that the fit of the veneering coating was not optimal and had to be adapted in the laboratory leading to a locus minoris resistentiae in this particular FDP. The evaluation of this major veneering ceramic fracture was not possible as the patient had already had it repaired before the follow-up visit, and therefore the reasons for the chipping may only be vaguely assumed.

Mechanical advantage is one likely benefit of the CAD/CAM (CAD-on) veneering technique for zirconia-ceramic FDPs. Another factor may be the efficiency and economic benefit of a digital workflow for the dental laboratory with respect to the fabrication of zirconia-ceramic FDPs. This factor was not within the scope of the present study but could be investigated further in the future.

In general, literature on the outcomes of CAD/CAM veneered reconstructions is presently very scarce. One in-vitro study compared the stability of CAD/CAM (CAD-on) zirconia-ceramic crowns and manually veneered zirconia-ceramic crowns after artificial aging. In this study significantly higher stability and lower fracture rates were observed in the CAD-on group.²¹

It might be assumed that the chipping risk increases with the number of connected reconstruction units. Single-unit CAD-on reconstructions might be less prone to chipping than multiple-unit FDPs. One possible explanation may be differences in strain between framework and veneering cover at single and multiple units at loading. If so, it might be assumed that the CAD/CAM (CAD-on) veneering of multiple-unit FDPs would exhibit better outcomes if designed as separate single veneering covers for each unit. However, this assumption is hypothetical and needs to be analyzed in future research. In the present study the tested CAD-on and manually veneered zirconia FDPs similarly exhibited problems with the veneering ceramic. In contrast to the test group, however, the problems occurring in

the control group were all major fractures of the veneering ceramic. In order to fully conclude on the two types of veneering ceramics for zirconia, a longer follow-up period and more clinical investigations are needed.

CONCLUSION

At 1 year of observation time the newly developed CAD-on zirconia-ceramic FDPs and the conventionally veneered zirconia-ceramic FDPs exhibited similar clinical outcomes. The 1-year survival rate was 100% for both. Both types of reconstructions exhibited problems of the veneering ceramic at similar amounts. However, the CAD/CAM veneering ceramics only exhibited minor superficial chipping whereas the layered veneering ceramics exhibited major fractures of the veneering ceramic. Longer observation periods and more clinical research are needed to fully elucidate and understand the outcomes of the new CAD/CAM veneered zirconia-ceramic FDPs.

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