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ORIGINAL ARTICLE

Clinical results of lithium-disilicate crowns after up to 9 years of service

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Abstract
Objectives The purpose of this prospective study was to evaluate the clinical outcome of anterior and posterior crowns made of a lithium-disilicate glass–ceramic framework material (IPS e.max Press, Ivoclar Vivadent).
Materials and methods A total of 104 single crowns were placed in 41 patients (mean age, 34±9.6 years; 15 male, 26 female). Eighty-two anterior and 22 posterior crowns were inserted. All teeth received a 1-mm-wide chamfer or rounded shoulder preparation with an occlusal/incisal reduction of 1.5–2.0 mm. The minimum framework thickness was 0.8 mm. Frameworks were laminated by a prototype of a veneering material combined with an experimental glaze. Considering the individual abutment preconditions, the examined crowns were either adhesively luted (69.2 %) or inserted with glass–ionomer cement (30.8 %). Follow-up appointments were performed 6 months after insertion, then annually. Replacement of a restoration was defined as failure.
Results Four patients (10 crowns) were defined as dropouts. For the remaining 94 crowns, the mean observation time was 79.5 months (range, 34–109.7 months). The cumulative survival rate according to Kaplan–Meier was 97.4 % after 5 years and 94.8 % after 8 years. Applying log rank test, it was shown that the location of the crown did not significantly have an impact on the survival rate (p=0.74) and that the cementation mode did not significantly influence the occurrence of complications (p=0.17).
Conclusions The application of lithium-disilicate framework material for single crowns seems to be a reliable treatment option.
Clinical relevance Crowns made of a lithium-disilicate framework material can be used clinically in the anterior and posterior region irrespective of an adhesive or conventional cementation when considering abutment preconditions.

Keywords All-ceramic · Single crowns · Lithium-disilicate · Survival rate · Clinical performance · Cementation mode

Abbreviations

FDPs	Fixed dental prostheses
NRT	Number of restored teeth
Rest	Restoration
Compl	Complication
Estim. surv	Estimated survival rate
cem	Cementation
endo	Endodontical

Introduction

Natural esthetic rendition is a primary aim after restoring teeth with full-coverage crowns. Therefore, an ideal dental material for the fabrication of crowns would allow the control of substrate color and translucency [1].

Traditional metal–ceramic crowns exhibit a lack of light exchange with the surrounding soft tissues caused by the reflection of their metal frameworks and their opaque layers. As a result, they often present a compromised esthetic appearance compared to natural teeth [2].

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All-ceramic restorations admit increased light transmission and diffusion [3] and consequently achieve better esthetic outcomes. It was also shown that all-ceramic restorations provide beneficial biocompatibility [4–6]. Hence, in the last years, all-ceramic restorations have increasingly become an alternative to conventional metal–ceramic restorations.

Nevertheless, due to long-term experience, metal–ceramic restorations are most established. Thus, the clinical outcome of metal–ceramic crowns is used as a gold standard and guideline when assessing the outcome of all-ceramic systems.

Investigating the clinical outcome of all-ceramic systems, it must be considered that aging and stress fatigue in the oral environment, as well as function and para-function, have an effect on the longevity of all-ceramic restorations [7]. Therefore, it is well established in the dental literature that evaluation considering a minimum of 5 years of clinical service is the gold standard [8, 9].

There are few studies reporting long-term clinical data. In general clinical studies show a tendency to higher fracture rates when crowns are placed in the posterior region [10, 11]; furthermore, molar crowns reveal higher failure rates than those on premolars [12].

All-ceramic systems can be categorized into two groups: those based on silica–ceramic which offer high translucence and excellent esthetic results associated with reduced tensile strength and those based on oxide ceramic that consist of an opaque high-strength core onto which esthetic layering ceramic must be applied to accomplish a natural appearance [1, 13].

Examples of translucent ceramic core materials are leucite-reinforced glass–ceramic (IPS Empress, since 2004: IPS Empress Esthetic, Ivoclar Vivadent, Schaan, Principality of Liechtenstein), translucent oxide ceramic In-Ceram Spinell (Vita Zahnfabrik, Bad Säckingen, Germany), or lithium-disilicate glass–ceramic (IPS Empress 2, Ivoclar Vivadent) [14]. For IPS Empress Esthetic and In-Ceram Spinell, high survival rates were shown for anterior crowns [15–17]. IPS Empress 2 reveals a long-term satisfactory clinical outcome of anterior and posterior crowns [18–21].

More opaque high-strength core materials are glass-infiltrated alumina (In-Ceram, Vita Zahnfabrik), densely sintered alumina (Procera AllCeram, Nobel Biocare, Göteborg, Sweden), and zirconia-based ceramics. Both, In-Ceram and Procera AllCeram crowns exhibit reliable cumulative survival rates in the anterior as well as in the posterior region [10, 20, 22, 23]. In medium terms, clinical studies on single crowns made of zirconia-based frameworks (NobelProcera, Nobel Biocare, IPS e.max ZirCAD, Ivoclar Vivadent) exposed promising resistance to fracture of the core [24, 25]

In order to combine durability with excellent esthetics, a reformulated pressable lithium-disilicate glass ceramic named IPS e.max Press (Ivoclar Vivadent) was developed and presented to the market. According to its manufacturers, it simultaneously provides enhanced mechanical properties and improved translucency. The range of indication is supposed to include anterior and posterior teeth. IPS e.max Press not only can be used as core material with esthetic layering but also allows ceramic crowns to be fabricated fully anatomical without the need for veneering (staining technique) [26, 27]. Until now, long-term clinical data concerning anterior and posterior crowns made of IPS e.max Press are not available. The primary aim of the present study was to assess the clinical outcome of veneered IPS e.max press crowns after a service of at least 5 years when the cementation mode (adhesive or conventional) is chosen after precise assessment of the abutment preconditions (precondition-oriented cementation).

Material and methods

Forty-one patients (mean age, 34±9.6 years; 15 male, 26 female), referred to the Department of Prosthodontics and Dental Materials of RWTH Aachen University with the indication for single crowns, were recruited for the clinical study. The requirements of the Helsinki Declaration were observed, and patients gave informed consent. The ethical board of the RWTH Aachen University has reviewed and approved the study design (no. 1083).

Patients that suffered from bruxism, poor oral hygiene, or periodontal diseases were not included. A maximum tooth mobility of grade 1 (maximum horizontal mobility of 1 mm) [28] was accepted. The prospective abutment teeth had to be vital or state-of-the-art endodontically treated.

Between August 2001 and December 2004, a total of 104 restorations containing 82 (78.9 %) anterior and 22 (21.1 %) posterior crowns were inserted. Seventy-two (69.2 %) crowns were adhesively luted (IPS Ceramic etchant/Monobond S/dual-cured Variolink II, Ivoclar Vivadent) and 32 (30.8 %) crowns were inserted with glass–ionomer cement (Vivaglass, Ivoclar Vivadent) (Fig. 1).

Prosthodontic procedures

All dental technicians involved in this study were trained by experts of the manufacturer. Five trained and calibrated clinicians performed the patients' treatment. All clinicians were fully informed about the study's protocol including the rationale, objectives, and design. All clinical processes were monitored by the principal investigator. The abutment teeth were prepared as follows:

- The location of the finishing line was oriented on the clinical conditions, either subgingival, equigingival, or supragingival.
- Margin design, 1-mm-wide rounded shoulder/chamfer.

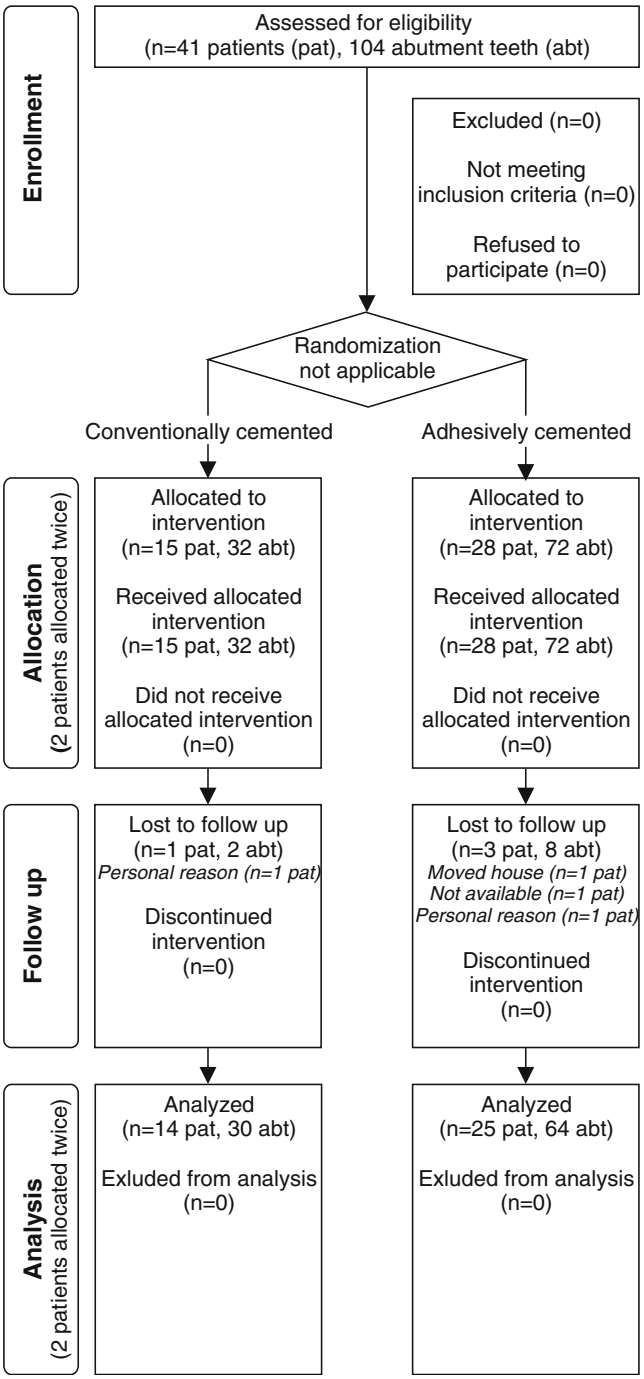

Fig. 1 The Consort E-Flowchart of the 41 enrolled patients (*pat*) and their 104 abutment teeth (*abt*)

- Equatorial reduction, 1.5 mm.
- Occlusal/incisal reduction, 1.5–2 mm.
- Total occlusal/incisal convergence, 6–15°.
- Particular attention was paid to rounded line angles.
- Abutment height varied between 3 and 6 mm depending on the amount of sound hard tooth tissue.

Following the tooth preparation, direct temporary crowns were fabricated (Protemp 2, 3M Espe, Seefeld, Germany) and placed with eugenolfree temporary cement (Provicol, VOCO, Cuxhaven, Germany).

At the next appointment, the temporary crowns were removed, and retraction cords (Ultrapak, Ultradent Products, USA) were placed according to the double-layer technique. For this purpose, a thin retraction cord (size 000, Ultrapak) was placed in the sulcus, and a second retraction cord was placed above (size 1, Ultrapak). The upper retraction cord was removed after 10 min. Impressions were made with a simultaneous, dual-mix technique using the polyether material (Permadyne, 3M Espe). An interocclusal registration was made with self-polymerizing polyvinyl siloxane (Futar D, Kettenbach Dental, Eschenburg, Germany).

In the dental laboratory, the impressions were cast with type IV gypsum (GC-Fuji Rock EP, Leuven, Belgium). The abutment teeth's angles of convergence were assessed using a parallelometer. A die spacer (Vita In-Ceram die spacer, Vita Zahnfabrik) was applied twice on the model die with a distance of 1 mm from the preparation line. The crowns were waxed to their proper shape. Afterwards, this full wax up was systematically reduced in order to provide space for veneering material (cut back technique). Particular attention was paid to achieve a minimum framework thickness of 0.8 mm. These wax patterns were invested with a special investment material (IPS PressVest Speed, Ivoclar Vivadent). The wax burnout took place in a conventional pre-heated furnace at 850°C. Then, in a press furnace (EP600 Ivoclar Vivadent), a ceramic ingot (IPS e.max Press) was plastified and pressed under vacuum into the mold of the investment. After divesting, minor adjustments for repositioning the pressings on their model dies were performed, if necessary. In this case, fine-grained diamond instruments with water-cooling spray at a maximum speed of 15,000 rpm were used.

During the next appointment, the fit of crown framework was evaluated intraorally (Fit & Test, VOCO, Cuxhaven, Germany). For adjustments, diamond burs with 30–40 μm diamond coating were used (contra-angle handpiece; 100,000 rpm; water application, 50 ml/min). After try-in, the frameworks were prepared for the firing process with a prototype version of a fluorapatite veneering material (Ivoclar Vivadent). According to the manufacturer, the frameworks were air-blasted with aluminum oxide (50-μm grain size) at 1 bar pressure, cleaned with steam jet and dried with oil-free air. After wash firing, veneering ceramic was applied by layering technique.

The anatomically shaped crowns were tried in. The occlusal and approximale contacts were marked and adjusted, if necessary. The contemporary restorations were cemented again, and the crowns were finished in the laboratory by additional veneering, if required. An experimental glaze and its firing completed the veneering process.

Cementation mode selection was performed according to the following guidelines (precondition-oriented cementation protocol):

Adhesive technique (IPS Ceramic etchant/Monobond S/ Variolink II, Ivoclar Vivadent) was preferred in the following situations:

- Abutment height of 4 mm or less.
- Angle of convergence more than 10°.

Conventional cementation with glass–ionomer cement (Vivaglass, Ivoclar Vivadent) was used in the following situations:

- Angle of convergence less than 10°.
- Abutment height of more than 4 mm.
- Patients with allergy to the components of the adhesive technique.
- The working field was located in an area difficult to isolate.

In the case of adhesive cementation, absolute isolation was performed by rubber dam, if possible. Otherwise, relative isolation and the placement of a retraction cord (size 0, Ultrapak, without impregnation) were used for moisture control. Adhesive and conventional cementation was conducted according to the manufacturers' instruction for use.

If occlusal adjustments were necessary after cementation, diamond burs with 30–40 μm diamond coating were used (contra-angle handpiece; 100,000 rpm; water application, 50 ml/min). The ground surfaces were polished using special ceramic polishers (Porcelain Prepolish (9545F 204 110) Komet, Lemgo).

Clinical examinations for baseline and follow-up data

Baseline data were recorded immediately after cementation. Follow-up appointments were performed 6 months after insertion, then annually.

There was one clinician that performed the recall examinations. Every finding (complication or failure) of a crown was additionally examined by the principal investigator.

During the appointments, the following parameters were assessed:

- Plaque index, gingival index, bleeding index, and probing depth of the abutment teeth
- Static and dynamic occlusal contacts as well as wear of the abutment teeth and the opposing teeth
- The kind of restoration, if renewed, of the opposing occlusal surface
- Biological complications such as loss of vitality joined by declined endodontical condition, endodontical disease, and occurrence of caries
- Technical complications such as loss of retention, minor chipping (the chipping is smaller or equal to 2×2 mm, and no core material is visible), major chippings (the chipping is larger than 2×2 mm, or the core material is visible), and fracture of the framework material

The necessity of replacement of a crown was rated as failure. The following criteria were determined for replacement:

- Fracture of the framework material
- Major chipping that was not repairable by composite material
- Caries of the abutment tooth
- Tooth loss because of biological complications (e.g., fracture of abutment tooth, endodontical infection)

Statistical analysis

The obtained data were evaluated using a statistical program (PASW Statistic 18, SPSS Inc., Chicago, IL, USA). Descriptive statistics were applied to the data.

The cumulative Kaplan–Meier survival rate was determined by considering only the replacement of the restoration (failures). The Kaplan–Meier rate of complication-free crowns was determined by considering failures as well as less severe complications (chipping of the veneering material, loss of retention, endodontical treatment). These analyses were calculated from the cementation date to the end of the latest follow-up visit and to the latest date of status known of participants who dropped out of the study.

The following methods were applied by assuming proportional hazards: Kaplan–Meier analysis and log rank tests were computed in order to identify if the location of crowns (anterior vs. posterior) had an influence on the survival of the crowns. Likewise, it was tested if the cementation mode (adhesive vs. conventional) had a significant impact on the occurrence of complications. Furthermore, Cox's proportional hazards model was applied in order to estimate the risk of failure in terms of location (anterior vs. posterior) and the risk of complication in terms of cementation mode (adhesive vs. conventional). The level of significance was set at 5 %.

Results

Four patients (10 crowns) were defined as dropouts, because they did not take part in recall examinations for more than a year. The remaining 94 restorations included 74 (78.7 %) anterior and 20 (21.3 %) posterior crowns; 64 (68.1 %) of them were luted adhesively, and 30 (31.9 %) were inserted with glass–ionomer cement (Table 1, Fig. 1). The mean observation time was 79.5 months (range, 34–109.7 months).

The 5-year recall was performed for 62 crowns, the 6-year recall for 59 crowns, the 7-year recall for 54 crowns,

Table 1 Distribution of the 94 evaluated crowns

	Right							Left						
NRT		2		1	6	14	17	18	14	5	2	2	3	1
Tooth	17	16	15	14	13	12	11	21	22	23	24	25	26	27
Tooth	47	46	45	44	43	42	41	31	32	33	34	35	36	37
NRT												2	5	2

Tooth restored tooth (numbering system: FDI), *NRT* number of restored teeth by single crowns

the 8-year recall for 27 crowns, and the 9-year recall for 6 crowns.

Technical complications

There were five rated technical complications (5.3 %). Three crowns (3.3 %) suffered from minor chipping of the veneering material. Major chippings did not occur. One chipping affected the edge and slightly the frontal aspect of an anterior crown. It took place after 31 months of clinical service. Two chippings appeared on the palatal marginal aspect of one patient's anterior crowns. These chippings happened after 6 and 92.6 months, respectively. After chipping, the ceramic surfaces were smoothened by polishing. Two crowns (2.1 %) fractured (Fig. 2). One of them was an incisor crown. A crack line was noted after 92.6 months. It had progressed from the palatal margin to approximately two thirds of the crowns' height (Fig. 2a). The other fracture was found in a molar after 101.2 months of clinical service. The crack line was on the palatal aspect. It was extended from the distal margin to the fissure that separates the palatal cusps and ended on the occlusal surface (Fig. 2b). During the clinical trial, the experimental glaze material failed in regard to a perfect surface. The first evaluation data from the Department of Prosthodontics and Dental Materials of RWTH Aachen University considering reduced surface smoothness gave reason to the manufacturer to not field this product and to improve the compounding. There was no loss of retention observed.

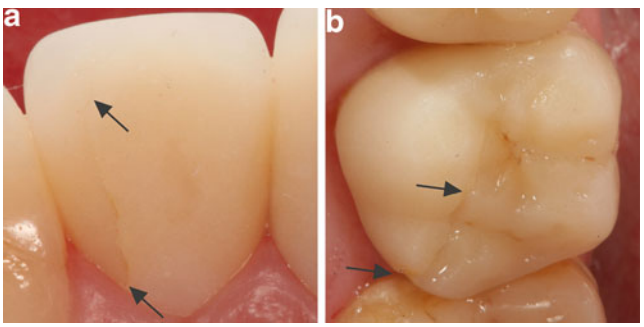

Fig. 2 Failures due to fracture. **a** Crack line from the palatal margin to approximately two thirds of the crowns' height of an incisor crown after 92.6 months of clinical service. **b** Crack line from the distal–palatal margin to the occlusal surface of a molar crown after 101.2 months of clinical service

Biological complications

There were four biological complications (4.3 %). Two anterior crowns (2.1 %) had to be treated endodontically 94.7 months after insertion. The access hole for the root canal fillings was sealed with composite resin filling material. Both crowns are still in function. One incisor (1.1 %) suffered from secondary caries located on the margin of its crown. Due to huge damage, this tooth had to be extracted 58.6 months after restoration. One tooth (1.1 %) that was already treated with a post and core developed an endodontical infection. After apicoectomy was performed, recurring disorders indicated extraction 40.2 months after cementation of the crown. During the observation time, none of the abutment teeth suffered from periodontal disease (probing pocket depth by periodontal probe ≤4 mm).

Failures

Four severe complications (4.3 %) were rated as failures. They include two technical complications (2.1 %) containing two fractures (2.1 %) (Fig. 2) and two biological complications (2.1 %) involving one secondary caries (1.1 %), and one apical infection (1.1 %) as described in detail above.

The corresponding survival rate for all restorations was 97.4 % after 5 years and 94.8 % after 8 years of clinical service (Table 2, Fig. 3). The cumulative survival rates for anterior and posterior crowns were 93.8 % and 100 %, respectively, after 8 years (Fig. 3). Applying log rank test, it was calculated that the location of the crown did not significantly have an impact on the survival rate (p=0.74). Moreover, Cox's proportional hazards model resulted in a hazard ratio (HR) of 0.68 when using “anterior crowns” as the reference group. This indicates that an anterior crown is 0.68 times as likely to fail at any time as a posterior crown, i.e., the risk associated with an anterior location appears to be much lower. However, the 95 % confidence interval (95% CI) (0.07–6.63) contains 1, indicating that there may be no difference in risk of failure associated with the use of either anterior or posterior crown [29].

Considering failures as well as less severe complications, the Kaplan–Meier rate of all complication-free crowns was 95.3 % after 5 years and 82.9 % after 8 years. The complication-free rates for adhesively and conventionally cemented crowns were 82.0 and 87.1 %, respectively, after

Table 2 Chronological listing of the complications and the respective impact on the survival according to Kaplan–Meier estimation

Patient's gender	Patient's age	Tooth	Character of rest./compl.	Time (months)	Failure	Crowns left	Estim. surv.
f	26	22	Adhesive cem.	6			
			Minor chipping				
			In situ				
f	38	11	Conventional cem.	31			
			Minor chipping				
			In situ				
f	28	21	Conventional cem.	40	×	89	0.989
			Extraction				
			Replaced				
m	26	21	Conventional cem.	58	×	67	0.974
			Caries				
			Replaced				
f	26	11	Adhesive cem.	93	×	36	0.948
			Fracture				
			In situ by request				
f	26	21	Adhesive cem.	93			
			Minor chipping				
			In situ				
f	53	21	Adhesive cem.	95			
			Endo. treatment				
			In situ				
f	53	22	Adhesive cem.	95			
			Endo. treatment				
			In situ				
m	38	26	Conventional cem.	101	×	22	0.907
			Fracture				
			Replaced				

Tooth restored tooth (numbering system: FDI); *Character of rest./compl.* cementation mode, type of complication, and status; *Time (months)* number of months of clinical service until complication; *Failure* assessment, if complication is a failure; *Crowns left* number of restorations that achieved a longer clinical service and are still being observed; *Estim. surv.* estimated survival rate for all crowns at this point of time (1=survival of the entire cohort)

8 years (Fig. 4). Using log rank test, it was shown that the cementation mode did not significantly influence the occurrence of complications (p=0.17). Calculating the hazard ratio for complications concerning adhesive and conventional cementation, affirming results were found (HR=0.41; reference group: "adhesive cementation," 95 % CI=0.11–1.56),

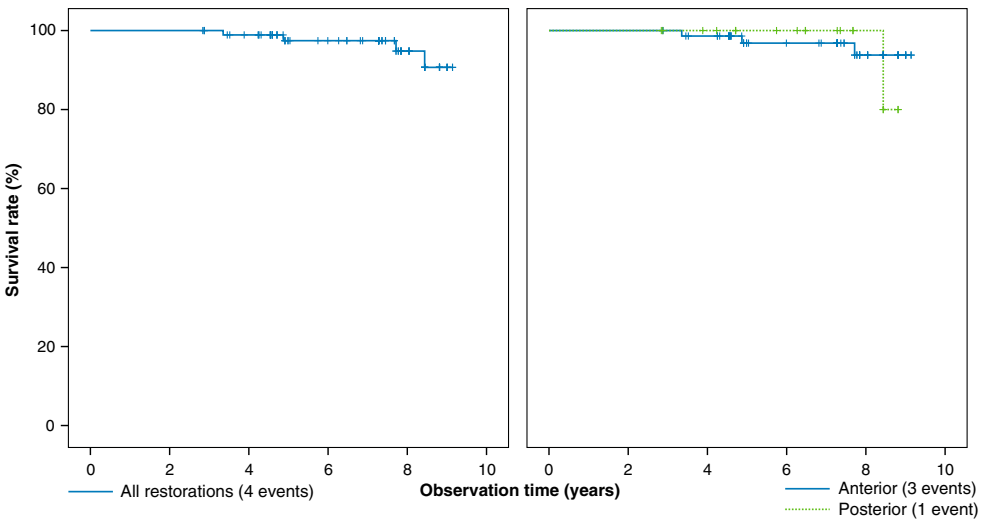

Fig. 3 The survival analysis according to Kaplan–Meier estimation for all restorations shows a survival of 90.7 %; the survival analysis regarding the crowns' position shows a 93.8 % survival for anterior and an 80.0 % survival for posterior crowns. The log rank test calculated that the location of the crown did significantly have an impact on the survival rate (p=0.74)

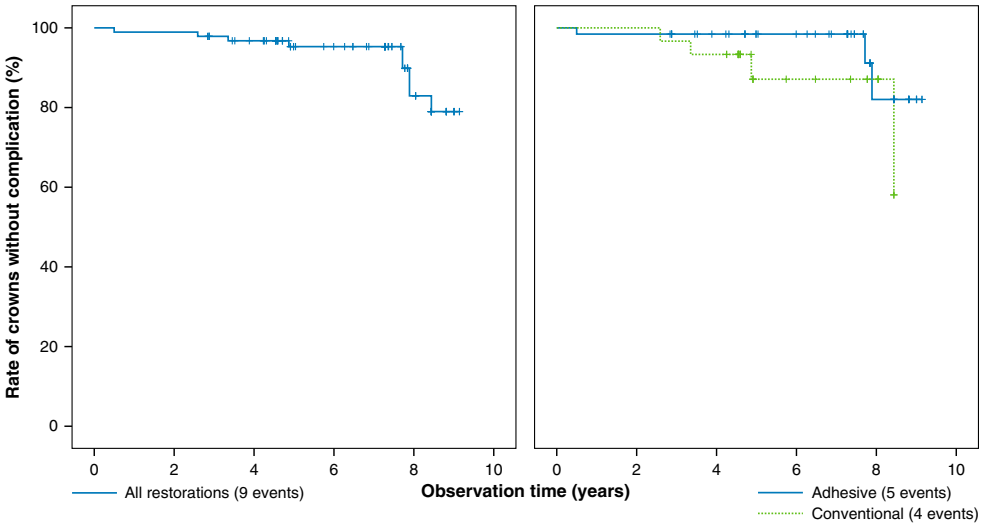

Fig. 4 The complication-free analysis according to Kaplan–Meier estimation shows that 77 % of the crowns were free of any complication. The complication-free rate for adhesively cemented crowns was 79.5 %; for conventionally cemented crowns, it was 58.1 %. The log rank test calculated that the cementation mode did not significantly influence the complication-free rate (p=0.25)

indicating that there may be no difference in the risk of complications associated with the mode of cementation [29].

Discussion

The primary aim of the present study was to assess the clinical outcome of single crowns after a service time of at least 5 years. Therefore, patients in need of full-coverage tooth restoration in the anterior and the posterior region were included in the study. In order to meet the demands for optimized esthetics, a prototype of a fluorapatite veneering material was applied onto the lithium-disilicate framework.

Four failures (4.3 %) were rated for computing the survival rate: two crack lines, one dental caries, and one endodontical disease. The anterior crown that developed a palatal crack line was probably stressed by intense anterior guidance. The other fracture was found in a posterior crown. In clinical examinations, there was neither evidence of premature occlusal contacts nor of posterior guidance during lateral movements of the lower jaw. The tooth that was extracted because of secondary caries had been treated with a root post before baseline of this study. The patient did not participate regularly on the recall appointments. That is why a possible lack of marginal integrity was not recognized at an early stage. The tooth that was extracted for endodontical reasons had received a dental post prior to the study as well. It has to be pointed out that in this case, the endodontical infection is a host response likely unrelated to the ceramic material used in the study. Only two failures were due to putative weakness of the framework material. These fractures evolved during the 8th and 9th years of observation time. This might indicate that for lithium-disilicate ceramic, the incidence of fractures presumably increases after a certain time of clinical service. Thus, it can be concluded that there is no constant annual failure rate. This particularly has to be considered when extrapolating short-time results.

In contrast to other studies on all-ceramic crowns [10, 11] in this study, the location of lithium-disilicate crowns did not significantly have an impact on the survival rate (log rank test, p=0.74 (Fig. 3); Cox's proportional hazards model, 95 % CI=0.07–6.63). In the present study, altogether nine complications (9.6 %) of any kind were observed. Consequently, it was estimated that 82.9 % of the crowns were free of any complication after 8 years (Fig. 4). Investigating the clinical quality of all-ceramic restorations, some studies used United States Public Health Service (USPHS) criteria [30, 31]; others used the Californian Dental Association (CDA) criteria [19, 23, 24, 32–34]. In the present study, USPHS or CDA criteria were not assessed, because when the study design was conceptualized, a differentiation between minor and major chippings of the veneering material was considered to be essential. This determination is not included in the USPHS/CDA criteria [35, 36]. Regarding retention of a crown and secondary caries, standardized modified CDA criteria were used for evaluation. Anyhow, this can be assumed as a limiting factor.

Further, there was only one clinician that performed the recall examinations. Following the USPHS/CDA criteria, this can be rated as a limiting factor of this study, too. On the other hand, the consistency of a single observer might contribute to reasonable valuation, especially when the observer was monitored by the principal investigator.

In the dental literature so far, there are few long-term studies concerning crowns made of high-strength frameworks. For a comparison of the clinical outcomes presented, it has to be taken into consideration that there is a lack of conformity concerning the listing of complications and the definition of “failure.”

A systematic review reports on a 5-year survival rate of 94.5 % for crowns made with glass-infiltrated alumina cores (In-Ceram, Vita Zahnfabrik) and 96.4 % for crowns made with pure alumina cores (Procera AllCeram, Nobel Biocare) [10]; lithium-disilicate cores were not separately listed. Actual long-term studies supplement the aforementioned results:

A recently published retrospective study on In-Ceram crowns (726 crowns) shows a survival rate of 96.2 % after 5 years and 92.6 % after 10 years [20]. Summing up, in 23.3 % of the crowns, complications which led to failure or those that had minor effects were noticed after 10 years. Procera AllCeram crowns are represented by two prospective studies. One study (135 crowns) reports on a survival rate of 100 % in the anterior region and 98.8 % in the posterior region after 5 and 7 years [22]; altogether for 11.1 % of the crowns, complications of any kind were mentioned. The other study (75 crowns) states a 5-year survival rate of 90.2 % [23] and, for 16% of the crowns, more or less severe complications.

Lithium-disilicate cores (IPS Empress 2, Ivoclar Vivadent) are represented in two retrospective studies (299 and 261 crowns, respectively). They describe a survival rate of 96.8 % after 5 years and 95.5 % up to 10 years [19, 20] as well as the general occurrence of complications in 10.4 and 3.1 % of the crowns, respectively.

Therefore, it can be broadly summarized that crowns made of high-strength materials exhibit a survival rate of 90.2–96.8 % after 5 years of clinical service. The complication rate after 10 years ranges from 3.1 to 23.3 %.

Metal–ceramic crowns are considered to be the gold standard. By means of Poisson regression, a 5-year survival rate of 95.6 % was determined [10]. A recent assessment of metal–ceramic crowns (539 crowns) shows an estimated survival rate of 94 % after 10 years of clinical service [37]; altogether, 21 (3.9 %) complications were identified. It can be concluded that the results of the present study are comparable with those of ceramic high-strength core materials and metal ceramic crowns, although there generally seems to be a tendency of smaller complication rates in metal–ceramic crowns.

So far, there is only one clinical trial published on IPS e.max Press crowns (Ivoclar Vivadent). A medium-term prospective study concerning 30 monolithic posterior crowns shows a survival rate of 96.6 % after 3 years of clinical service [27]. As a failure, there was one fracture detected. It extremely slowly originated from a crack line and therefore resembles the fractures observed in the present study. The author assumes that the rod-shaped crystals in the ceramic might act as crack stoppers. Concerning the capability of fabricating monolithic fixed dental prostheses (FDPs) made of IPS e.max Press, one prospective study exhibits an 8-year survival rate of 93 % [26]. In this study, the use of either glass–ionomer or resin cement did not influence the failure or complication rate.

The primary function of cementation is to establish reliable retention, a durable seal of the space between the tooth and the restoration, and to provide adequate optical properties. Due to solubility, the use of water-based cement such as glass–ionomer cement strongly depends on macroretentive preparation design and excellent marginal fit. Adhesive luting materials exhibit negligible solubility and improved esthetic effects. By creating a hybrid layer formation, resin cement is also capable of providing long-term stability for non-retentive restorations [38]. Summarizing, the advantage of adhesive luting originates from the creation of a compound system between ceramic, dentin, and luting agent. The essential requirements for obtaining this compound system are good access to the working field and absolute moisture control [39]. In this study, the decision for either conventional cementation or adhesive luting was based on a concise evaluation of the abutment preconditions. An individual decision like this is reasonable, because “lege artis” cementation of adhesive cements requires sufficient isolation. On the other hand, a small angle of convergence and large bonding surfaces allow sufficient bond strength of conventional cements. Therefore, a randomization according to the different cements was not adequate. Using the cementation protocol of this study, it was shown that the cementation mode did not significantly influence the incidence of complications (log rank test, 0.17 (Fig. 4); Cox's proportional hazards model, 95% CI=0.11–1.56). Additionally, it is remarkable that there was no loss of retention reported. Summing up, this result does not provide a “right” or “wrong” regarding the choice of cement, but might recommend a precise assessment of the working conditions.

Finally, it has to be mentioned that the log rank test as well as Cox's proportional hazards model require the assumption of proportional hazards [29]. As the graphs of the survival (anterior vs. posterior) and complications (adhesively vs. conventionally cemented) cross, the time factor might influence the individual hazards. Anyhow, for most of the observation time, the proportional hazard assumption is appropriate; therefore, the use of log rank test and Cox's proportional hazards model seems reasonable. The application of extended Cox models might provide more detailed information [40].

In other long-term in vivo studies investigating cementation of lithium-disilicate frameworks, similar results were shown for crowns [21] and 3-unit FDPs [26].

Conclusion

It can be summarized that anterior and posterior crowns made with lithium-disilicate framework material (IPS

e.max Ivoclar Vivadent) had a cumulative survival rate of 97.4 % after 5 years and 94.8 % after 8 years of clinical service. The location of the crowns (anterior versus posterior) did not significantly compromise the survival. Using a precondition-oriented cementation protocol, the type of cementation (conventionally versus adhesively) had no significant influence on the incidence of any complications. The application of lithium-disilicate framework material for single crowns seems to be a reliable treatment option.

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Conflict of interest The authors declare that they have no conflict of interest.

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