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Retrospective study of glass-ceramic single tooth restorations after up to 15 years

Introduction: Glass-ceramic single-tooth restorations count among the standard treatments in dental practice at present owing to their good esthetics, biocompatibility and survival rates. The aim of this study was to investigate the occurrence of various long-term complications based on data collected from a general dental practice.

Material and methods: A retrospective analysis of 1132 posterior single-tooth restorations made of Empress 2 and IPS e.max ceramic from 251 patients was performed. The restorations were placed between 2000 and 2015 by a single dental practitioner in a private general dental practice. The minimum observation period was 2 years. The patient records were examined for the following complications: fracture, root canal treatment, periodontal complications, occlusal adjustment procedures to correct occlusal interferences, postoperative hypersensitivity, secondary caries and decementation. The statistical analysis was based on the ceramic used (Empress 2 and IPS e.max) and the type of restoration (inlay, partial crown, or crown).

Results: Twelve of the 769 Empress 2 and 3 of the 363 IPS e.max restorations failed due to bulk fracture. There was no significant difference between the materials ($p = 0.411$). Crowns displayed a significantly higher fracture rate compared to inlays or partial crowns ($p = 0.02$ and $p = 0.04$), irrespective of material. Empress 2 restorations showed a significantly higher incidence (3.6 %) of premature occlusal contacts requiring adjustment compared to IPS e.max restorations (1.4 %) ($p = 0.037$). No correlation between occlusal adjustment procedures and fracture was observed ($p = 0.426$). Empress 2 crowns had a significantly higher probability of decementation ($p < 0.001$) compared to Empress 2 inlays or partial crowns. Teeth with IPS e.max restorations exhibited significantly more postoperative hypersensitivitity ($p < 0.001$) and required root canal treatment significantly more frequently ($p = 0.041$) than teeth with Empress 2 restorations. Periodontal complications occurred significantly more often in teeth with IPS e.max crowns than in teeth with IPS e.max inlays or partial crowns ($p = 0.005$). The incidence of secondary carious lesions was not significantly higher neither with respect to material nor type of restoration.

Conclusion: Both glass-ceramic materials are suitable for everyday use in dentistry; IPS e.max and Empress 2 restorations demonstrated good long-term clinical results and an acceptable amount of complications. The most common complications were postoperative hypersensitivity, fractures and periodontal complications. The number of complications was higher for crowns than for inlays or partial crowns.

Keywords: glass-ceramic; IPS e.max; Empress 2; single-tooth restorations; complications; long-term performance; retrospective; fracture rate

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1 Introduction

All-ceramic single-tooth restorations constitute an integral part of the dental treatment spectrum nowadays due to their good esthetics, biocompatibility and very good long-term results in terms of survival probability [2, 14, 21, 38, 41].

The greatest difficulty lies in their lack of mechanical stability and strength, which is determined, in particular, by the pronounced brittle fracture properties and the low tensile load-bearing capacity [35]. The resulting fractures and chipping present a major challenge for dental practice and research. Yet, great progress has been made in this field in recent decades. With the introduction of leucite and lithium disilicate ceramics Empress 1 and 2 at the end of the 1980s and early 1990s, the slow crack growth that is especially problematic for glass-ceramics was significantly reduced through the incorporation of mechanically more stable leucite and lithium disilicate crystals.

Although great improvements have been made with regard to the parameters that influence glass-ceramic materials such as material properties and luting materials, a large number of studies do not include other factors which are involved in the failure process and incidence of complications [12, 13, 31, 36]. It is known that, in addition to the material's inherent properties, dentogenic, patient-related and dentist-dependent factors also influence the survival probability of restorations [5, 22].

The aim of this retrospective study was to provide a practice-oriented analysis of the complications of glass-ceramic inlays, partial crowns and crowns made of Empress 2 and IPS e.max Press. With this in mind, the incidence of the complications fracture, decementation, endodontic treatment, postoperative hypersensitivity, periodontal complications, occlusal interferences requiring occlusal adjustment procedures and secondary caries was investigated in relation to the type of restoration (inlay, partial crown, and crown) and material (Empress 2, IPS e.max). The null hypothesis stated that the incidence of complications was stochastically independent of the type of restoration (inlay, partial crown, crown) and material (Empress 2, IPS e.max).

2 Material und methods

2.1 Study design and complications

The patient collective was selected from a private general dental practice. All glass-ceramic single-tooth restorations made of Empress 2 or IPS e.max which were placed between 01.01.2000 and 31.12.2015 were included in the study. Data was collected retrospectively based on the procedure's respective billing code. The inclusion criteria were: glass-ceramic single-tooth restorations in the posterior region (first premolar to third molar) made of the materials Empress 2 and IPS e.max from Ivoclar Vivadent, a minimum observation period of 2 years and a minimum patient age of 18 years.

The complications fracture, decementation, postoperative hypersensitivity, secondary caries, premature occlusal contacts, periodontal complications and root canal treatment were evaluated according to a yes/no format. Together with the complications, the material (IPS e.max and Empress 2) and the type of restoration (inlay, partial crown and crown) were also recorded.

The complications were defined as follows: fracture was defined as chipping of the ceramic which lead to the restoration's failure and the subsequent need for a new one. Chipping that did not require restoration renewal was not included in the study.

Root canal treatments after a restoration was placed were recorded regardless of whether restoration renewal was needed. Periodontal complications comprised of all the situations in which the patient required systematic periodontal therapy in the area of the restored tooth after the restoration's placement. Premature contacts requiring adjustment and postoperative hypersensitivity were recorded up to 4 months after the restoration was placed.

The recording of secondary caries ensued when it resulted in restorative treatment in the form of a new filling or restoration.

The study project was registered by the Ethics Committee of the University of Bonn under number 274/20 and approved on 16.06.2020.

2.2 Treatment procedure

The patients stemmed from a private general dental practice and all the treatments were performed by a single dentist. Likewise, all the restorations were fabricated in the practice's dental laboratory by a single dental technician.

Before the start of treatment, the dental examination and periodontal status were recorded and a clinical functional analysis was completed for each patient. Depending on the diagnosis, conservative treatment, professional tooth cleaning/periodontal treatment or functional therapy were performed as part of the pretreatment. After, prosthetic treatment ensued.

The preparation design of inlays and partial crowns took the size of the defect into account and made use of rounded inner edges. Cusps were included in the preparation design of partial crowns and rounded, 1 mm wide shoulder margins were prepared. The marginal design of crowns was also performed as a 1 mm wide circular chamfer preparation with rounded inner edges. Tooth substance removal was between 1.5–2 mm occlusally and 1.5 mm circumferentially and the taper was 6–10°. The preparation margin was positioned supragingivally, equigingivally or subgingivally according to the clinical conditions. Special attention was given to the preparation of rounded edges.

A one-step double mix impression using the double cord technique was made with the polyether material Impregum 3M ESPE. Occlusal registration was performed either in the maximum intercuspidation or in the centric condylar position based on the requirements of each individual case. The restorations were fabricated in the Ivocalr EP 600 Combi press furnace according to the manufacturer's instructions. The enamel was etched with 30–40 % phosphoric acid and the restoration was conditioned for 20 seconds with 5 % hydrofluoric acid before its cementation. The ce-

mentation was made using the Syntac Classic adhesive system (Ivoclar Vivadent) and one of the following dual-curing adhesive luting materials: Variolink 2 (Ivoclar Vivadent), RelyX (3M Espe), G-Cem (GC), Panavia SA (Kuraray), Tetric Evo Flow (Ivoclar Vivadent), Filtek Supreme (3M Espe) or PermaCem (DMG). When the circumstances permitted, rubber dam was used during the cementation procedure. In cases where occlusal adjustments were needed, this was performed – after cementation – with a diamond-coated round or football bur. Subsequently, the restorations were polished intraorally with diamond grit ceramic polishers (Komet, Germany).

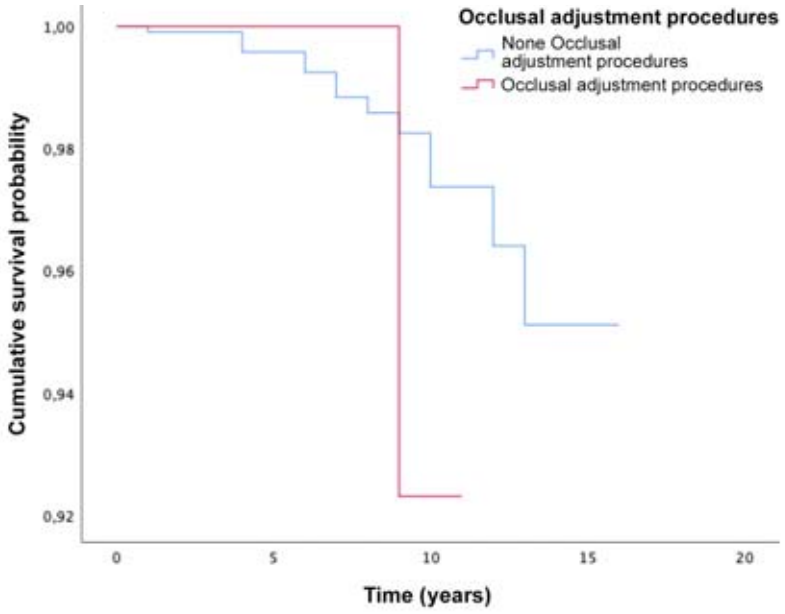
2.3 Statistical analysis

The statistical analysis and graphical representations were made using the SPSS software for Windows, version 24.0 (SPSS Inc., U.S.A.). The data were evaluated descriptively and expressed as percentages and absolute numbers in order to express the incidence of complications comparatively between the restoration types (inlay, partial crown, crown) and between the materials (Empress 2, IPS e.max). The chi-square test and the Fisher exact test, in the case of low numbers, were applied in order to compare the incidence of complications among the restoration types (inlay, partial crown, crown) and materials (Empress 2, IPS e.max). The effect of adjustment procedures on the survival of glass-ceramic single-tooth restorations was investigated using Kaplan-Meier analyzes and the significance was determined using the log rank test. Differences between the groups were determined as being significant at $p < 0.05$.

3 Results

A total of 1132 restorations from 251 patients were evaluated. The mean observation period was 6.5 ± 3.3 years.

Overall, 363 restorations were made of IPS e.max and 769 of Empress 2. The mean ages of patients with Empress 2 and IPS e.max restorations were 46.6 (± 10.31) and 51.46 (± 12.29) years, respectively. The number of restorations placed in male and female patients was 455 and 677, respectively. The total of 1132 restorations consisted of 331 crowns (Empress 2 n = 215, IPS e.max n = 116), 487 partial crowns (Empress 2 n = 315, IPS e.max n = 172) and 314 inlays (Empress 2 n = 239, IPS e.max n = 75). Before the start of treatment, 1065 vital and 65 avital abutment teeth were present. A list of the data is found in Tables 1 and 2.



Tab. 1 and 2, Fig. 1: Kathinka Offer

Figure 1 Kaplan-Meier diagram showing the survival probability of restorations which did and did not require occlusal adjustment procedures due to premature contacts.

3.1 Fracture

Over the course of the observation period, 15 restorations failed due to fracture. Twelve (1.6 %) were made of Empress 2 and 3 (0.8 %) of IPS e.max. The fracture rate between Empress 2 and IPS e.max restorations is not significantly different ($p = 0.411$).

With respect to the type of restoration, 10 crowns (3 IPS e.max, 7 Empress 2) and 5 partial crowns made of Empress 2 fractured. Crowns made of Empress 2 and IPS e.max fractured significantly more frequently ($p < 0.04$ and $p < 0.02$) than partial crowns and inlays made of the same material (see Tables 1 and 2).

Furthermore, only one out of 33 restorations needing adjustment due to premature contacts fractured. This corresponds to a survival probability of 97.0 % in the group with adjustment procedures and 98.7 % in the group without. The p value of 0.426 indicates that the differences between the two groups are not significant (Fig. 1).

3.2 Root canal treatment

Altogether, 18 (1.6 %) of the 1132 teeth underwent root canal treatment after the restoration was placed. Eight (0.7 %) restorations were made of IPS e.max and 10 (0.9 %) of Empress 2. The difference between the materials is statistically significant at $p = 0.041$ (see Tables 1 and 2).

In comparing the different types of restorations, no significant difference with regard to the need for root canal treatment existed, neither for Empress 2 nor for IPS e.max.

3.3 Decementation

Nine of the 769 Empress 2 (1.2 %) and none of the 363 IPS e.max restorations became loose. No statistically significant difference between the materials existed (see Tables 1 and 2).

In terms of the type of restoration, only crowns made of Empress 2 became loose ($p < 0.001$).

3.4 Periodontal complications

Periodontal deterioration subsequent to restoration placement with the

	all restorations		IPS e.max		IPS e.max		P
	n	%	n	%	n	%	
Number of treatments	1132	100	769	67.9	363	32.1	–
Fractures							
Total	15	1.3	12	1.6	3	0.8	0.411
Crowns	10	0.9	7	3.3	3	2.6	–
Partial crowns	5	0.4	5	1.6	0	0	–
Inlays	0	0	0	0	0	0	–
Root canal treatment							
Total	18	1.6	8	**0.7**	10	0.9	**0.041**
Crowns	8	0.7	3	1.4	**5**	4.3	
Partial crowns	8	0.7	5	1.6	3	1.7	
Inlays	2	0.2	0	0	2	2.7	
Decementation							
Total	9	0.8	9	**0.8**	0	0	**0.041**
Crowns	9	1.2	9	4.2	**0**	0	
Partial crowns	0	0	0	0	0	0	
Inlays	0	0	0	0	0	0	
Periodontal complications							
Total	13	1.1	8	0.7	5	0.4	0.766
Crowns	6	0.5	1	0.5	**5**	4.3	
Partial crowns	0	0	5	1.6	0	0	
Inlays	0	0	2	0.8	0	0	
Secondary caries							
Total	8	0.7	8	0.7	0	0	0.061
Crowns	2	0.1	2	0.9	**0**	0	
Partial crowns	3	0.3	3	1	0	0	
Inlays	3	0.3	3	1.3	0	0	
Occlusal adjustment procedures							
Total	33	2.9	28	**2.4**	5	0.5	**0.037**
Crowns	13	1.1	8	3.7	**4**	3.6	
Partial crowns	16	1.4	15	4.8	1	0.6	
Inlays	5	0.4	5	2.1	0	0	
Postoperative hypersensitivity							
Total	72	6.3	23	**2**	49	4,3	**0.000**
Crowns	39	3.4	7	3.3	**32**	27,6	
Partial crowns	24	2.1	10	3.2	14	8,1	
Inlays	9	0.8	6	2.5	3	4	

Table 1 Complications consisting of fractures, root canal treatment, decementation, periodontal complications, secondary caries, occlusal interferences and postoperative hypersensitivity for Empress 2– und IPS e.max restorations

need for systematic periodontal therapy was observed for 8 out of 769 and 5 out of 363 teeth with Empress 2 and IPS e.max restorations, respectively. No statistically significant correlation between the material ($p = 0.766$) and periodontal deterioration was seen.

In the case of IPS e.max restorations, crowns showed periodontal complications significantly more frequently ($p = 0.005$) than partial crowns or inlays made of the same material (see Tables 1 and 2).

3.5 Secondary caries

Eight of the 769 Empress 2 and none of the 363 IPS e.max restorations developed secondary carious lesions during the observation period.

Neither the comparison of materials nor the comparison of restoration type showed statistically significant differences ($p > 0.061$) (see Tables 1 and 2).

3.6 Premature contacts requiring adjustment

Empress 2 restorations required occlusal adjustment procedures significantly more frequently ($p = 0.037$) than IPS e.max restorations (28 of 769 versus 5 of 363).

The type of restoration, on the other hand, had no significant influence on the need for occlusal adjustment procedures (see Tables 1 and 2).

3.7 Postoperative hypersensitivity

Postoperative hypersensitivity occurred significantly more frequently in teeth with IPS e.max restorations ($p = 0.001$) compared to teeth with Empress 2 restorations (49 out of 363 restorations versus 23 out of 769 restorations).

IPS e.max crowns exhibited a higher risk of postoperative hypersensitivity than partial crowns and inlays in this study (see Tables 1 and 2).

4 Discussion

The incidence of complications was evaluated as a function of material and the type of restoration. The results can serve as a decision-making aid for the dental practitioner when

selecting the material and type of restoration.

4.1 Fracture

There were no significant differences between the fracture rates of Empress 2 and IPS e.max restorations in this study. However, significant differences between the restoration types were seen ($p < 0.04$). Crowns made of both materials showed a significantly higher probability of fracturing than inlays or partial crowns. A possible explanation for this may be the increase in defects per area; with increasing restoration size, the microcracks and pores responsible for failure also increase [35].

Furthermore, in vitro studies have shown that partial crown preparations have a very favorable stress distribution pattern under load [7]. This may, in combination with the predominantly enamel limited preparation [34], explain the significantly better fracture rates of partial crowns and inlays.

In addition to the inherent defects of the material, sufficient material layer thickness and the adhesive bond, the correct preparation also has a fundamental influence on the clinical success of glass-ceramic restorations [11, 19, 33]. Due to the retrospective study approach, it is not possible to track the material layer thicknesses and whether the preparation was appropriate for the material. An incorrect, possibly too angular, preparation and/or too little tooth substance removal for glass-ceramic crowns may also explain their increased fracture rates compared to partial crowns and inlays.

The results found in literature correspond to those presented here with respect to the fracture rates of IPS e.max restorations [23], while the results on the fracture rates of Empress 2 restorations are significantly lower in this study compared to those reported in literature [12]. For example, a 10-year study on the survival probability of IPS e.max restorations by Malament et al [23] showed a fracture rate of 0.3 %. However, in addition to single-tooth restorations, the study included three-unit bridges and one-wing adhesive bridges. No differentiation was made between the various types of restorations in terms of the fracture rates.

	Crown		Partial crown		Inlay		P
	n	%	n	%	n	%	
Total fractures	10	0.9	5	0.4	0	0.0	
Empress 2	7	3.3	5	1.6	0	0.0	**0.020**
IPS e.max	3	2.6	0	0.0	0	0.0	**0.040**
Total root canal treatments	8	0.7	8	0.7	2	0.2	
Empress 2	3	1.4	5	1.6	0	0.0	0.158
IPS e.max	5	4.3	3	1.7	2	2.7	0.042
Total decementations	9	0.8	0	0.0	0	0.0	
Empress 2	9	4.2	0	0.0	0	0.0	**0.000**
IPS e.max	0	0.0	0	0.0	0	0.0	–
Total periodontal complications	6	0.5	5	0.4	2	0.2	
Empress 2	1	0.5	5	1.6	2	0.8	0.427
IPS e.max	5	4.3	0	0.0	0	0.0	**0.005**
Total secondary caries	2	0.1	3	0.3	3	0.3	
Empress 2	2	0.9	3	1.0	3	1.3	0.925
IPS e.max	0	0.0	0	0.0	0	0.0	–
Total occlusal adjustment procedures	13	1.1	16	1.4	5	0.4	
Empress 2	8	3.7	15	4.8	5	2.1	0.251
IPS e.max	4	3.6	1	0.6	0	0.0	0.064
Total postoperative hypersensitivity	39	3.4	24	2.1	9	0.8	
Empress 2	7	3.3	10	3.2	6	2.5	0.870
IPS e.max	32	27.6	14	8.1	3	4.0	**0.000**

Table 2 Separation of complications between the restoration types for Empress 2 and IPS e.max.

The fracture rate of 0.8 % of Empress 2 restorations was significantly lower in the present study compared to the values between 1 % and 15.6 % reported in literature [8, 10]. However, it should be taken into account that the study design varied considerably. In a prospective 12-year study by Frankenberger et al [12], for example, a fracture rate of 12.5 % for Empress 2 inlays and onlays was seen. However, in their study, in addition to the fracture rates, the influence of different luting materials was investigated as well. It was found that restorations fractured more frequently when they were cemented with a light-curing adhesive luting material compared to a dual-curing luting material [12]. However, the fracture rates were determined independently of the luting material [12]. Since only dual-curing luting materials were used in the current study, this may be a possible reason for the better results. In a retrospective 11-year long study by Fradeani et al. [10] on the fracture rate of leucite-reinforced glass-ceramic crowns, a fracture rate of 15.6 % was reported for posterior restorations over the study period. Only crowns were investigated in their study. However, the results in this current study suggest that significant differences exist in the survival rates of different single-tooth restorations (inlays, partial crowns and crowns). Since this study determined that crowns fractured significantly more frequently than partial crowns or inlays, and Fradeani et al. [10] exclusively investigated crowns, this may explain the considerably lower values.

A meta-analysis by El-Mowafy et al. [8] investigating the survival probabilities and long-term clinical performance of Empress 2 restorations showed slightly lower survival rates for Empress 2 crowns (ranging from 92 % to 99 % after 3–3.5 years) compared to inlays and partial crowns (ranging from 91 % and 96 % after 4.5–7 years). These results correspond most closely to the results of the current study.

In literature, it has been reported that, in addition to the degradation (or corrosion) of silicate ceramic materials, adjustment procedures with the associated development of new crack nuclei are often responsible for the failure of a restoration [19]. However, literature on this topic is inconsistent: in a study by Ludovichetti et al. [20], no negative influence on the fracture strength of IPS e.max and Lava Ultimate (Vita Enamic) samples was found after grinding and polishing procedures, even after mechanical aging. In contrast, Schmitter at al. [29] demonstrated a reduced fracture strength (560.6 ± 233.3 N vs. 535.5 ± 128.0 N) for zirconia crowns in the anterior region after incisal adjustment procedures. This could not be confirmed in the current study. The survival probability of restorations that underwent adjustment procedures was 97.0 % compared to 98.7 % for restorations that did not undergo adjustment procedures ($p = 0.426$). Further clinical studies on this topic are needed to draw definitive conclusions.

The results of current study suggest that there is a relationship between fracture rate and restoration size. Since crowns fractured significantly more frequently than inlays and partial crowns, it is advisable to perform a risk analysis prior to prosthetic planning and material selection in order to be able to set the course for a more durable restoration in good time. Since the reasons for a fracture cannot be understood in detail retrospectively, the adherence to material thickness is once again emphasized.

4.2 Root canal treatment

In this study, root canal treatment was performed significantly more frequently ($p = 0.045$) on teeth with IPS e.max restorations than on teeth with Empress 2 restorations. No significant difference was determined when differentiating between the restoration types inlay, partial crown and crown.

A limited amount of literature exists regarding endodontic complications for glass-ceramic restorations. Failure rates due to endodontic complications are reported to be between 0.2 % and 2 % for IPS e.max restorations [17, 30] and these are thus slightly lower than in current study.

The degree of tooth substance destruction and the proximity of the defect to the dental pulp before restoration were not recorded in this study. Since a correlation to the restorative material is rather improbable, it would be useful for future studies to consider other influencing factors such as the extent of the defect, the indications for restorative treatment, the etching and adhesive system used and the luting material.

Despite significant differences between the materials, both Empress 2 as well as IPS e.max restorations display a low risk of requiring root canal retreatment.

4.3 Decementation

In the present study, 9 Empress 2 crowns and no IPS e.max restorations became loose. The difference between the types of restorations was statistically significant for Empress 2 restorations ($p = 0.001$), whereas there was no significant difference with respect to material. Crowns made of Empress 2 loosened significantly more frequently than partial crowns or inlays made of the same material.

In literature, few comparable studies exist so far. In a study by van den Breemer et al. [41], 2 of 73 (1.2 %) lithium disilicate restorations became loose over a period of 15 years. Thereby, loosening was the third most frequent failure cause after fracture and secondary caries. In a systematic literature review, van den Breemer et al. [40] also showed that the bond strength of glass-ceramic restorations is significantly lower when the bond is purely in dentin compared to the bond in enamel. Since the dentin wound is greatest when crowns are prepared and it further decreases from the partial crown to the inlay, this may potentially explain the higher decementation rates of Empress 2 crowns that were determined in this study.

Likewise, the decementation of Empress 2 restorations has only been discussed in a few studies to date. This may be due to the fact that the loosening of a restoration – with its possible recementation – was not considered a failure, and thus, remains unspecified in a large number of studies.

Teichmann et al. [37] reported a decementation rate of 6.9 % after 10 years in a prospective study on the complication and survival rates of lithium disilicate restorations. These results are considerably higher than the values of 1.1 % after 15 years determined in the present study. In their study, Teichmann et al. included both conventionally and adhesively cemented restorations. In the current study, dual-curing adhesive luting materials were exclusively used to cement the restorations. This may be a reason for the different results. Studies have demonstrated repeatedly that the shear, tensile and bond strengths of adhesive luting materials are significantly superior to those of conventional luting cements [3, 4, 24, 26, 40]. Given that the decementation rates of conventionally cemented glass-ceramic restorations differ significantly from adhesively luted cements [25], this can explain the different results.

The results of the current study suggest that, apart from the influences described in literature regarding surface conditioning, the luting material applied and the remaining tooth substance [25, 40], the shape of the restoration can also have an influence on decementation of the restoration.

However, since the position of the crown margin (supragingival or subgingival) was not recorded in this study, and given that its position has a significant influence on the likelihood of absolute moisture control, and consequently on the possibility of errors occuring during adhesive cementation, it is advisable to integrate it in future studies.

4.4 Periodontal problems

Five of 111 teeth which were treated with IPS e.max crowns showed periodontal complications. Teeth with partial crowns and inlays made of the same material were not affected. Crowns therefore exhibited periodontal complications significantly more frequently ($p = 0.005$) than inlays or partial crowns.

No significant differences existed between the Empress 2 and IPS e.max materials.

These results are concordant with recent literature. Ababnaeh et al. [1] determined that Class II restorations exhibited the highest probing depths as well as the highest plaque index, Class V restorations showed the highest attachment loss and crowns displayed the highest gingival index in the area of the restoration margin. All of these restorations have the preparation margin localized near the cementoenamel junction, free gingiva and subgingival area in common.

In the present study, other influencing factors such as the applied luting material, the adhesive system, the position and integrity of the crown margin and the plaque index were not included. Due to the retrospective design, these factors could not be obtained from the patient records with the necessary consistency and methodology which is required for clear evaluation. In the current study, only the need for systemic periodontal therapy was considered a criterion for periodontal complications. Further information such as the PSI, the plaque index, the attachment level or the position and integrity of the crown margin can be helpful in order to include and differentially consider the multifactorial influences that can lead to damage.

Nevertheless, ceramic restorations generally show a high biocompatibility and are described as being very well tolerated periodontally [1]. This is reflected in this study. Hence, periodontal treatment was required in only 1 % of all Empress 2 and 1.4 % of all IPS e.max restorations.

4.5 Secondary caries

Secondary caries required treatment in 1 % of all Empress 2 restorations and in none of the IPS e.max restorations. They therefore represent the rarest complication. No statistically significant differences existed between the materials, Empress 2 and IPS e.max, and the various types of restorations.

In various meta-analyses [8, 39], secondary caries represented the most frequent complication of glass-ceramic restorations.

Since sociodemographic factors are known to influence caries prevalence [6, 16], they may possibly represent a cause for the discrepancy in results between literature and this study. The patient collective in this study stemmed from a private dental practice; a more sociodemographically diverse patient collective would be desirable in future studies. In addition, the collection of patients' plaque indices and oral hygiene habits could potentially provide information about patient-related influencing factors.

4.6 Premature occlusal contacts

There was a significant difference ($p = 0.037$) with regard to the premature occlusal contacts between Empress 2 (3.6 %) and IPS e.max (1.4 %). No differences existed with regard to the type of restoration.

In literature, the occlusal fit of IPS e.max restorations is rated as being very good [9]. Comparable studies for Empress 2 restorations are not available in literature.

It should be taken into account that the number of placed restorations has an influence on the need for premature occlusal contacts to be adjusted. In patients that required occlusal adjustments, an average of 8.8 restorations were placed, whereas in patients without the need for occlusal adjustments, an average of only 4.5 were placed. This indicates that, in addition to the material, the number of restorations can also have an influence on occlusal interferences.

An increased number of restorations is also indicated in the case of changes in the occlusion. The sagittal and vertical rehabilitation of the occlusion comprises of many intermediary steps which can contribute to cumulative occlusal defects. In this study, all patients who received glass-ceramic restorations due to a change in occlusion were pretreated with a splint. Bite registration was performed in the centric condylar position.

The causes for the reconstruction of the occlusion and tooth hard substance can be manifold; parafunctional abrasions and erosions represent a widespread indication. This should be considered given that patients, who already showed parafunctions before therapy, can also react more sensitively to disturbances in occlusion after.

In this study, 3 of the 7 patients with occlusal dysfunctions displayed signs of severe bruxism in the form of myopathy as well as occlusal wear facets not concordant with age, while another 2 of 7 patients displayed moderate bruxism. Only 2 patients showed no symptoms which would be indicative of this parafunction. Thus, in further studies, the connection between the indication for rehabilitation, the number of restorations and bruxism activity together with the occurrence of posttherapeutic occlusal interferences should also be investigated.

As discussed previously under the heading "4.1. Fracture" in this study, increased fracture rates could not be determined after occlusal adjustments were performed.

4.7 Postoperative hypersensitivity

Postoperative hypersensitivity was observed significantly more frequently for IPS e.max restorations, especially crowns, than for Empress 2 restorations.

In literature, similar results have been reported for Empress 2 restorations. In 2010, Van Dijeken et al. [42] described that persistent hypersensitivity lasted 2–4 weeks for 3 % of the restorations, while Krämer et al. [18] reported hypersensitivity in 4 % of Empress 2 inlays up to 4 years after placement. The restorations were adhesively cemented in both studies (Van Dijeken: three 3-step etch-and-rinse systems and two 2-step etch-and-rinse systems, Krämer: EBS Multi/Compolute [3M Espe] and Syntac/Variolink II).

Comparable studies are lacking for lithium disilicate ceramics. In a prospective 10-year study on three-unit bridges with a lithium disilicate ceramic framework, Solá-Ruiz et al. [32] determined reversible postoperative hypersensitivity in 14.3 % of cases. This would be consistent with the result obtained in this study.

Even if various causes for postoperative hypersensitivity exist, such as increased thermal conductivity of the restorative material or preparation close to the pulp, postoperative hypersensitivity is currently believed to be primarily associated with adhesive restorations or adhesive restorative materials.

The reason for this – according to the hydrodynamic theory of Brännström and Aström [15] – has to do with intratubular fluid movements which arise due to small gaps between dentin and composite. If the dentinal canals are not completely sealed by the applied bonding system, dentinal fluid can leak out and cause irritation of the A-δ fibers during occlusal loading.

The use of dual-curing adhesives and phosphoric acid is considered another risk factor for the occurrence of postoperative hypersensitivity [15]. However, since both phosphoric acid as well as dual-curing adhesive luting materials (Variolink II [Ivoclar Vivadent], G-Cem [GC], RelyX [3M Espe], Tetric EvoFlow [Ivoclar Vivadent], Panavia SA Cement [Kuraray], G-Cem [GC], Filtek Supreme [3M Espe], PermaCem [DMG]) were used to condition the tooth hard substance and cement the restorations for both types of restorative materials (IPS e.max and Empress 2) in this study, the significant differences with regard to hypersensitivity cannot be explained by this.

The cause for the differences between the types of restorations could be related to the size and depth of the dentin wound. Though the size of the dentin wound is greatest for crown preparation, it decreases progressively from partial crown to inlay. This is also reflected in the determined values.

Nevertheless, this does not explain the difference between the materials because no significant differences for Empress 2 restorations with 3.3 % of crowns, 3.2 % of partial crowns and 2.5 % of inlays were determined.

Since both Empress 2 and IPS e.max restorations showed very good results in terms of their biocompatibility, chemical resistance, cytotoxicity and sensitization potential in various studies [2, 27, 28], the toxicological properties inherent in the material appear unlikely to be the cause of postoperative hypersensitivity. There were no significant differences between Empress 2 and IPS e.max restorations with regard to the distribution of restoration type, patient age or gender; this may explain the increased hypersensitivity of IPS e.max restorations.

Due to the retrospective study design, it is no longer possible to thoroughly trace the differences with regard to the etching and adhesive systems applied. This may be a possible reason for the increased hypersensitivity of IPS e.max restorations.

5 Conclusions

In summary, both Empress 2 and IPS e.max restorations showed good clinical results and an acceptable level of complications in daily dental practice. Occlusal adjustments do not appear to increase the fracture rate of glass-ceramic restorations. Decreased bonding to the enamel surface, however, increases the risk of fracture, decementation, periodontal complications and postoperative hypersensitivity.

Postoperative hypersensitivity, root canal treatment and periodontal complications occurred significantly more frequently for IPS e.max than for Empress 2 restorations in this study.

Given the proven, very good toxicological properties of both ceramics [2, 27, 28], the results of this study suggest that further studies on glass-ceramic restorations should be conducted to explore factors which were not investigated in this study. These studies should consider factors such as the close proximity to the pulp and subgingival localization of restorations, as well as, the etching and adhesive systems or luting materials applied.

Conflict of interest

The authors declare that there is no conflict of interest as defined by the guidelines of the International Committee of Medical Journal Editors.

References

1. Ababnaeh KT, Al-Omari M, Alawneh TN: The effect of dental restoration type and material on periodontal health. Oral Health Prev Dent 2011; 9: 395–403

2. Anusavice KJ: Degradability of dental ceramics. Adv Dent Res 1992; 6: 82–89

3. Behr M, Rosentritt M, Mangelkramer M, Handel G: The influence of different cements on the fracture resistance and marginal adaptation of all-ceramic and fiber-reinforced crowns. Int J Prosthodont 2003; 16: 538–542

4. Burke FJ: The effect of variations in bonding procedure on fracture resistance of dentin-bonded all-ceramic crowns. Quintessence Int 1995; 26: 293–300

5. Burke FJ, Lucarotti P: Ten-year outcome of crowns placed within the General Dental Services in England and Wales. J Dent 2009; 37: 12–24

6. Dutra LDC, Barbos Neves ET, Morais de Lima LC et al.: Degree of family cohesion and social class are associated with the number of cavitated dental caries in adolescents. Braz Oral Res 2020; Apr 17;34:e037. doi: 10.1590/1807–3107 bor-2020.vol34.0037. eCollection 2020.

7. Edelhoff D, Beuer F, Güth JF: Vollkeramische Präparation und Farbnahme. https://www.zwp-online.info/fachgebiete/implantologie/grundlagen/vollkeramische-restauration-praeparation-und-farbnahme, 2013 (letzter Zugriff am 26.07.2020)

8. El-Mowafy O; Brochu JF: Longevity and clinical performance of IPS-Empress ceramic restorations – a literature review. J Can Dent Assoc 2002; 68: 233–237

9. Esqivel-Upshaw J, William R, Oliveira E, Yang M, Clark AE, Anusavice K: Randomized, controlled clinical trial of bilayer ceramic and metal-ceramic crown performance. J Prosthodont 2012; 33: 166–173

10. Fradeani M, Redemagni M: An 11-year clinical evaluation of leucite-reinforced glass-ceramic crowns: a retrospective study. Quintessence Int 2002; 33: 503–510

11. Frankenberger R, Möring G, Blunck U, Hajtó J, Pröbster L, Ahlers O: Präparationsregeln für Keramikinlays und -teilkronen unter besonderer Berücksichtigung der CAD/CAM Technologie.

Bayrisches Zahnärzteblatt 2008; https://www.bzb-online.de/apr08/45_51.pdf (letzter Zugriff am 26.07.2020)

12. Frankenberger R, Taschner M, Garcia-Godoy F, Petschelt A, Krämer N: Leucite-reinforced glass ceramic inlays and onlays after 12 years. J Adhes Dent 2008; 10: 393–398

13. Gehrt M, Wolfart S, Rafai N, Reich S, Edelhoff D: Clinical results of lithium-disilicate crowns after up to 9 years of service. Clin Oral Invest 2013; 17: 275–284

14. Guess PC, Selz CF, Steinhart YN, Stampf S, Strub JR: Prospective clinical split-mouth study of pressed and CAD/CAM all-ceramic partial-coverage restorations: 7-year results. Int J Prosthodont 2013; 26: 21–25

15. Haller B: Die postoperative Hypersensibilität. zm online 2009; 6

16. Krämer N, Lohbauer U, Frankenberger R: Adhesive luting of indirect restorations. Am J Dent 2000; 13: 60D–76D

17. Krämer N, Frankenberger R: Clinical performance of bonded leucite-reinforced glass ceramic inlays and onlays after eight years. Dent Mater 2005; 21: 262–271

18. Krämer N, Ebert J, Petschelt A, Frankenberger R: Ceramic inlays bonded with two adhesives after 4 years. Dent Mater 2006; 22: 13–21

19. Lohbauer U: Belastbarkeit von Keramiken – Ursachen für Frakturverluste. 2012; https://www.zwp-online.info/fachgebiete/zahntechnik/werkstoffe/belastbarkeit-von-keramiken-ursachen-fuer-fraktur verluste (letzter Zugriff am 26.07.2020)

20. Ludovichetti FS, Trindade FZ, Abado GL, Pezzato L: Effect of grinding and polishing on the roughness and fracture resistance of cemented CAD-CAM monolithic materials submitted to mechanical aging. J Prosthet Dent 2019; 121: 866.e1–866.e8

21. Mackert JR: Side-effects of dental ceramics. Adv Dent Res 1992; 6: 90–93

22. Malament KA, Socaransky SS: Survival of Dicor glass-ceramic dental restorations over 20 years: Part IV. The effects of combinations of variables. Int J Prosthodont 2010; 23: 134–140

23. Malament K, Natto ZS, Thompson V, Rekow D, Eckert S, Weber HP: Ten-year survival of pressed, acid-etched e.max lithium disilicate monolithic and bilayered complete-coverage restorations: Performance and outcomes as a function of tooth position an age. J Prosthet Dent 2019; 121: 782–790

24. Michelini FS, Belser UC, Sherrer S, De Rijk WG: Tensile bond strength of gold and porcelain inlays to extracted teeth using three cements. Int J Prosthodont 1995; 8: 324–331

25. Mobilio N, Fasiol A, Mollica F, Catapano S: Effect of different luting agents on the retention of lithium disilicate ceramic crowns. Materials (Basel, Switzerland) 2015; 8: 1604–1611

26. Peutzfeld A, Sahafi A, Flury S: Bonding of restorative materials to dentin with various luting agents. Oper Dent 2011; 36: 266–273

27. Roulet JH: Seitenzahnversorgung mit adhäsiv befestigten Keramikinlays. Quintessenz 1989

28. Schäfer R, Kappert HF: Die chemische Löslichkeit von Dentalkeramiken. Dtsch Zahnärztl Z 1993; 48: 625–628

29. Schmitter M, Lotze G, Bömicke W, Rues S: Influence of surface treatment on the in-vitro fracture resistance of zirconia-based all-ceramic anterior crowns. Dent Mat 2015; 31:1552–1560

30. Scientific Report IPS e.max, Ivoclar Vivadent 2013; 2: 9

31. Sjögren G, Lantto R, Granberg A, Sundström BO, Tillberg: A clinical examination of leucite-reinforced glass-ceramic crowns (Empress) in general practice: A retrospective study. Int J Prosthodont 1999; 12: 122–128

32. Solá-Ruiz MF et al.: Survival rates of a lithium disilicate-based core ceramic for three-unit esthetic fixed partial dentures: A 10-year prospective study. Int J Prosthodont 2013; 26: 175–180

33. Strub JRK, Türp JC, Witkowski S, Heydecke G, Wolfart S: Präparationstechnik – Werkstoffkundliche und konstruktionsbedingte Kriterien. Curriculum Prothetik Band II. Quintessenz Verlag, Berlin 2011; S. 452

34. Strub JRK, Türp JC, Witkowski S, Heydecke G, Wolfart S: Prinzipien bei Veneers und Teilkronen. Curriculum Prothetik Bank II. Quintessenz Verlag Berlin 2011; S. 677

35. Strub JRK, Türp JC, Witkowski S, Heydecke G, Wolfart S: Curriculum Prothetik Band II. Quintessenz Verlag, Berlin 2011

36. Taskonak B, Sertgöz A: Two-year clinical evaluation of lithia-disilicate-based all-ceramic crowns and fixed partial dentures. Dent Mat 2006; 22: 1008–1013

37. Teichmann M, Göckler F, Weber V, Yildrim M, Wolfart S, Edelhoff D: Ten-year survival and complication rates of lithium-disilicate (Empress 2) tooth-supported crowns, implant-supported crowns, and fixed dental protheses. J Dent 2016; 56: 65–77

38. Valenti M, Valenti A: Retrospective survival analysis of 110 lithium disilicate crowns with feather-edge marginal preparation. Int J Esthet Dent 2015; 10: 246–257

39. Vagropoulou GI, Klifopoulou GL, Vlahou SG, Hirayama H, Michalakis K: Complications and survival rates of inlays and onlays vs. complete coverage restorations: A systematic review and analysis of studies. J Oral Rehabil 2018; 45: 903–920

40. Van den Breemer CR, Gresnight MM, Cune MS: Cementation of glass ceramic posterior restorations: a systematic review. Biomed Res Int 2015; 2015: 148954. doi: 10.1155/2015/148954

41. van den Breemer CR, Vinkenborg C, van Pelt H, Edelhoff D, Cune MS: The clinical performance of monolithic lithium disilicate posterior restorations after 5, 10 and 15 years: A retrospective case series. Int J Prosthodont 2017; 30: 62–65

42. van Dijken JW, Hasselrot L: A prospective 15-year evaluation of extensive dentin-enamel-bonded pressed ceramic coverages. Dent Mat 2010; 26: 929–939

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