Clinical Performance of All-Ceramic Inlay and Onlay Restorations in Posterior Teeth

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Purpose: The aim of this clinical retrospective study was to evaluate the clinical performance and longevity of glass-ceramic onlays and inlays in stress-bearing posterior teeth. ***Materials and Methods:*** Five hundred forty-seven posterior teeth in the maxillae and mandibles of 120 patients (46 males, 74 females) were restored with 213 onlays, 38 single-surface inlays, 141 two-surface inlays, and 155 three-surface inlays between 1987 and 2009 at Innsbruck Medical University, Innsbruck, Austria, by two experienced dentists. The restoration sample included 9 (1.6%) nonvital teeth and 40 (33%) patients diagnosed with bruxism. The study population was examined clinically during regularly scheduled maintenance appointments. The risk of failure was determined using Kaplan-Meier survival analyses. ***Results:*** The mean observation periods for onlays and all inlays were 80 ± 34 months and 111 ± 63 months, respectively. Twenty-seven failures were recorded. The estimated survival rates for onlays and all inlays after 5, 10, and 12 years were 98.9% and 98.9%, 92.4% and 96.8%, and 92.4% and 89.6%, respectively. Nonvital teeth showed a significantly higher risk of failure ($P < .001$). There was no greater risk of failure associated with existing parafunction (bruxism) ($P = .408$). Restorations on premolars survived longer in the first 15 years than restorations on molars, but no statistical significance was found ($P = .913$). ***Conclusion:*** Glass-ceramic onlays and inlays were demonstrated to be successful in posterior teeth; however, at this time, their efficacy is inferior to that of cast gold restorations. *Int J Prosthodont 2012;25:395–402.*

Over the past decade, patients' demands for highly esthetic restorations, problems with the use of composite resins for large restorations in posterior teeth, and discussions regarding possible side effects of dental amalgam have led to increased interest in the use of all-ceramic inlays and onlays to restore posterior teeth.[1–7] Clinical studies on the success of stress-bearing all-ceramic inlays and onlays in permanent posterior teeth have already identified that the longevity of dental restorations is dependent on many different factors, including material-, patient-, and dentist-related factors.[5] However, improved all-ceramic materials, new bonding procedures, and use of composite resin cements have increased their use.[7]

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The most common problem associated with failure of ceramic inlays and onlays is fracture of the ceramic material.[2,5,8–11] It is recommended that ceramic restorations be carefully selected in patients where extensive occlusal loads are expected, such as in the rehabilitation of posterior teeth in patients who exhibit signs of parafunctional habits.[7,12,13] The Academy of Prosthodontics defines bruxism as the parafunctional grinding of teeth and an oral habit consisting of involuntary rhythmic or spasmodic nonfunctional gnashing, grinding, or clenching of teeth, in other than chewing movements of the mandible, which may lead to occlusal trauma.[14] Its prevalence is reported to be 20% among the adult population.[15] However, only limited information is available on the longevity of ceramic inlays and onlays in patients with bruxism habits.[16,17]

In this context, the present retrospective study evaluated the clinical performance and longevity of silicate glass-ceramic onlays and inlays in stress-bearing posterior teeth to find confounding factors other than the porcelain system used that might influence clinical performance. Therefore, over an observation period of 10 to 261 months, this study retrospectively evaluated the clinical performance

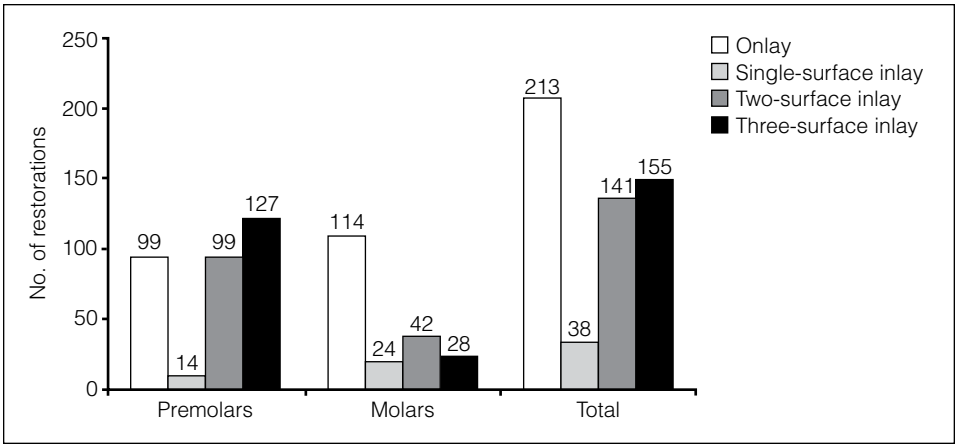


Fig 1 Distribution of restoration type according to tooth position.

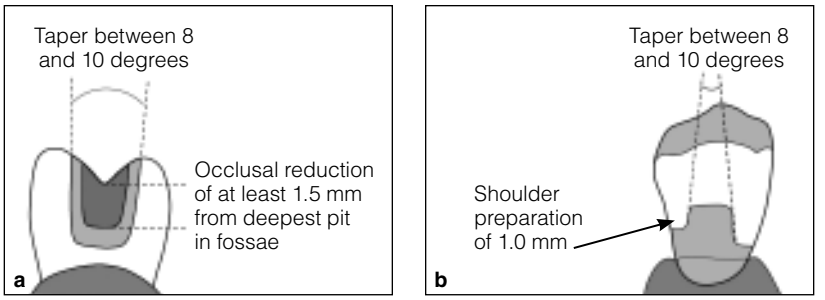


Fig 2 Ceramic preparation design. **(a)** Approximal view; **(b)** lingual view.

of all-ceramic restorations in premolar and molar regions placed in vital teeth and teeth with endodontic treatment as well as in patients with and without diagnosed bruxism.

Materials and Methods

The evaluated inlays and onlays were a subgroup from a long-term evaluation of 1,335 glass-ceramic restorations. A detailed description of the study design is available elsewhere.[18] In brief, 120 patients were examined during their regularly scheduled maintenance appointments at the Department of Restorative and Prosthetic Dentistry, Innsbruck Medical University, Innsbruck, Austria, as described.[18] The study population included 46 males (38.8%) and 74 females (61.7%). The restoration sample included 9 (1.6%) nonvital teeth, and 40 patients (33%) were diagnosed with bruxism. The mean age of patients at insertion of the all-ceramic restoration was 46.2 ± 12.5 years (range: 14 to 72 years). Parafunction (bruxism) was identified by means of direct questions and visual observation of the behavior. In instances of the absence of subjective awareness, past bruxism behavior was inferred from the presence of clear wear facets caused by clenching, gnashing, and grinding activities of the teeth not interpreted to be a result of masticatory function. No sleep laboratory recordings were performed. The clinical procedure and evaluation were similar to those described previously.[18]

The sample of posterior teeth included 547 glass-ceramic restorations comprising 213 (38.9%) onlays, 38 (6.9%) single-surface inlays, 141 (25.8%) two-surface inlays, and 155 (28.3%) three-surface inlays placed between November 1987 and December 2009 at the Department of Restorative and Prosthetic Dentistry, Innsbruck Medical University. The distribution of restored teeth and types of restorations are presented in Fig 1.

All-ceramic preparations were performed using slightly conical diamond burs (nos. 847KR-016 and -018, 848KR, A8847KR-016 and -018, A8848KR-016; Innsbruck Preparation Set, Brasseler) to develop a taper of approximately 8 to 10 degrees (Fig 2). The cavities were box-shaped with sharp-edged cavosurface angles for the occlusal margins and rounded shoulder preparations (minimum: 1 mm) for the axial surface margins. Additionally, a wide isthmus was prepared.

Concerning the internal form, all angles were rounded to smooth the preparation. An occlusal reduction of at least 1.5 mm from the deepest pit in the fossae was performed (Fig 2). Cavities with mesial or distal preparations were created interproximally so that contact with adjacent teeth was completely broken. The gingival margin was prepared entirely in enamel whenever possible following the gingival line. In teeth with deep subgingival preparations, no adhesive ceramic restorations were performed; the teeth were restored with cast gold inlays and onlays.

If a cusp was fractured or hopelessly undermined, the cusp was capped for onlay preparation. The functional cusps in premolars and molars were reduced approximately 1.5 mm. Nonfunctional cusps were reduced less than 1 mm. The restorations were fabricated with a range of glass-ceramic materials following the manufacturers' recommendations in the dental laboratory of the department. No dentin bonding was performed in 73 (13.3%) restorations; in the others, Optibond FL (Kerr; 83%) and Syntac Classic (Ivoclar Vivadent; 3.7%) were used. The restorations were cemented using the following materials: Optec cement (Jeneric/Pentron; n = 6, 1.1%), 3M Cement (3M ESPE; n = 60, 11%), Dual Zement (Ivoclar Vivadent; n = 6, 1.1%), and Variolink High Viscosity (Ivoclar Vivadent; n = 475, 86.8%). After cementation and finishing procedures under 2.5× magnification, occlusion was checked carefully and, if indicated, adjusted using canine-guided dynamic occlusion.

Statistical Analysis

Descriptive statistics are given as means, standard deviations, ranges, and frequencies. Survival of the posterior restorations was analyzed by means of Kaplan-Meier curves. For group comparisons, the log-rank chi-square statistic[19] was used. Restorations in patients diagnosed with bruxism were compared to those in nonbruxers, vital teeth were compared with nonvital teeth, teeth with previous endodontic treatment were compared to those with endodontic treatment after placing the ceramic restorations, and premolars were compared with molars. All statistical analyses were completed using SPSS 18.0 (IBM).

Results

In total, 547 ceramic restorations were evaluated in 120 patients. The restorations in both dental arches were observed over a 10-year period, with 144 restorations observed over 10 years, 58 restorations observed over 15 years, and 19 restorations observed over 20 years of function. The mean observation periods for the different restoration types are presented in Table 1.

Table 1 Mean Observation Period Based on Type of Restoration

	n	Mean ± SD (mo)	Range (mo)
Onlay	213	80 ± 34	12 to 160
Inlay (all)	334	112 ± 64	10 to 261
Single-surface	38	135 ± 88	10 to 254
Two-surface	141	109 ± 63	10 to 261
Three-surface	155	108 ± 56	13 to 246

SD = standard deviation.

Twenty-seven failures were recorded for the entire sample (547 restorations). The main reason for failure was of ceramic origin (fracture, crack, or chipping) in 11 (40.74%) restorations, followed by secondary caries in 8 (29.63%) (Table 2). Concerning the different restoration types, 5 failures were recorded in onlay restorations; 2 ceramic failures (fracture and chipping) occurred on functional cusps. Twenty-two failures occurred in inlay restorations: 1 failure in a single-surface inlay, 4 failures in two-surface inlays, and 17 failures in three-surface inlays. The number of failed and remaining restorations according to time and restoration type are presented in Table 3, and the estimated survival rates computed using Kaplan-Meier analysis are presented in Table 4. In terms of observation time, the survival at 12 years showed the best results for single-surface inlays (94.7%), followed by two-surface inlays (94.4%) and onlays (92.4%); the worst survival rate was noted for inlays with three surfaces (83.4%). Comparing all restoration types, no significant differences were found between the different types of inlays and onlays (log-rank test, $P = .669$). In addition, in the pairwise comparison, onlays showed better survival than inlays with three surfaces, but the statistical analysis showed no significance (log-rank test, $P = .204$).

There was no greater risk of failure associated with existing parafunction (bruxism) (log-rank test, $P = .408$). The different survival curves of patients with and without bruxism are presented in Figs 3a to 3d. Only one failure occurred in single-surface inlays. For this reason, no statistical analysis was performed for this restoration group.

The restoration sample included 9 (1.6%) nonvital teeth, on which 5 (55.6%) all-ceramic restorations failed. The survival curves for both groups are presented in Fig 4. Restorations on vital teeth showed significantly fewer failures than restorations on nonvital teeth ($P < .001$).

Table 2 Overview of the Failure Characteristics

	Onlays		Inlays (all)		Total	
	n	%	n	%	n	%
Ceramic factors	2	40.00	9	40.91	11	40.74
Fracture of the ceramic	1	20.00	6	27.27	7	25.93
Crack in the ceramic	0	0.00	3	13.64	3	11.11
Chipping	1	20.00	0	0.00	1	3.70
Caries	1	20.00	7	31.82	8	29.63
New restoration necessary after endodontic treatment	1	20.00	2	9.09	3	11.11
Marginal integrity	0	0.00	2	9.09	2	7.41
Esthetics, color	0	0.00	1	4.55	1	3.70
Fracture of the tooth	0	0.00	1	4.55	1	3.70
Hypersensitivity	1	20.00	0	0.00	1	3.70
Debonding	0	0.00	0	0.00	0	0.00
Total	5	100.00	22	100.00	27	100.00

Table 3 No. of Failed and Remaining Restorations

Survival time (y)	Onlays (n = 213)		Inlays (all) (n = 334)		Single-surface inlay (n = 38)		Two-surface inlay (n = 141)		Three-surface inlay (n = 155)	
	Failed	Remaining	Failed	Remaining	Failed	Remaining	Failed	Remaining	Failed	Remaining
5	2	148	3	258	0	25	0	109	3	124
8	3	62	7	186	0	21	0	75	7	90
10	5	25	8	119	0	20	0	52	8	47
12	5	4	15	75	1	17	2	28	12	30
15	–	–	17	58	1	14	2	24	14	20
18	–	–	20	35	1	10	2	13	17	13
20	–	–	20	19	1	8	2	6	17	5

– = no data.

Table 4 Estimated Survival for the Different Types of Restorations (%)

Survival time (y)	Onlays	Inlays (all)	Single-surface inlay	Two-surface inlay	Three-surface inlay
5	98.9	98.9	100.0	100.0	97.8
8	98.1	97.3	100.0	100.0	94.5
10	92.4	96.8	100.0	100.0	93.3
12	92.4	89.6	94.7	94.4	83.4
15	–	87.2	94.7	94.4	77.6
18	–	81.5	94.7	94.4	63.9
20	–	81.5	94.7	94.4	63.9

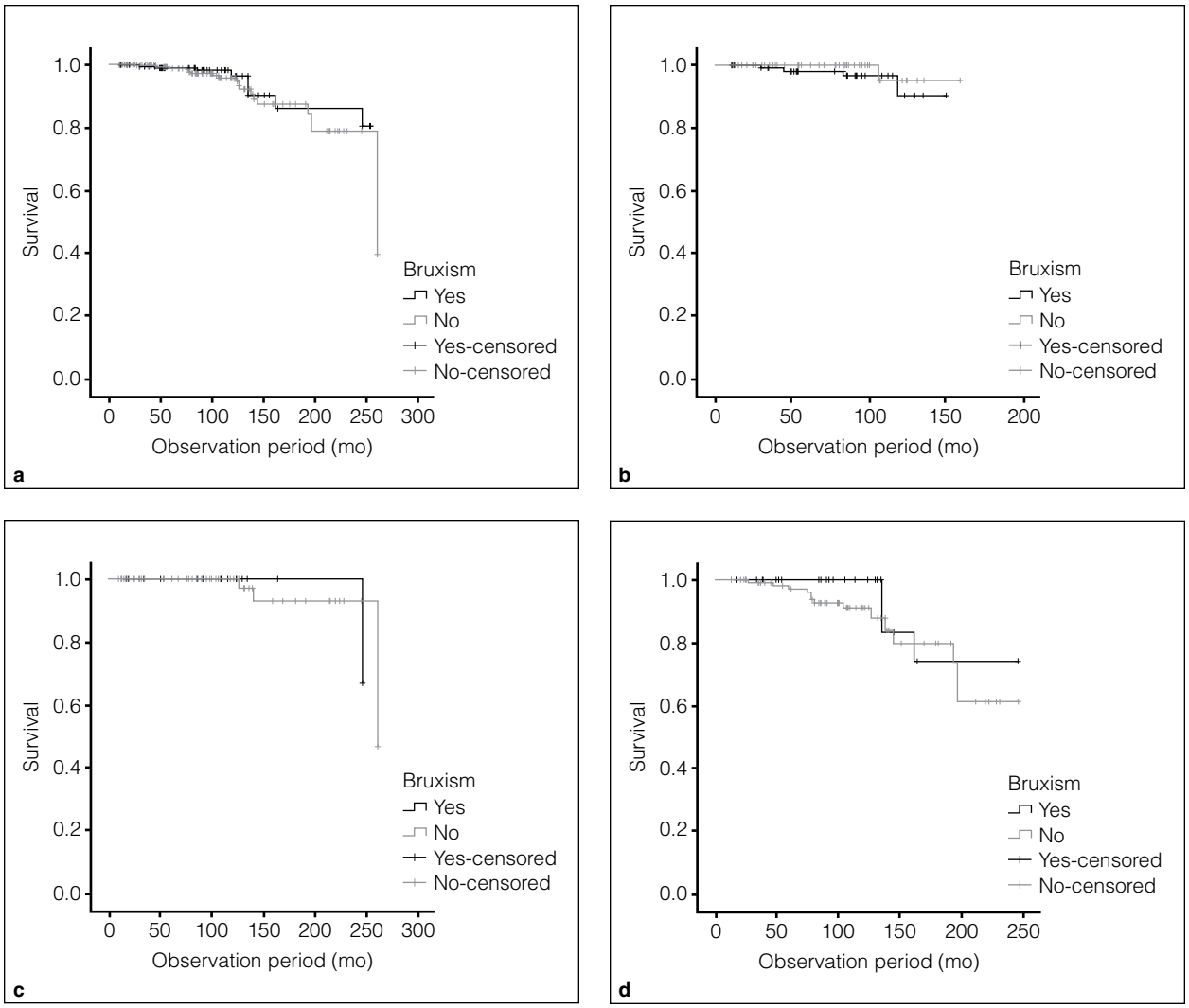
– = no data.

Endodontic treatment had to be performed after insertion of the ceramic in 7 (77.8%) restorations, but the log-rank group comparison revealed no significant differences between teeth with prior endodontic treatment and those with treatment after placing the ceramic restoration ($P = .158$).

Nine failures were recorded in molars and 18 in premolars. Restorations in premolars survived longer in the first 15 years of observation (Fig 5), but no statistically significant difference was found between premolars and molars with regard to survival ($P = .913$).

More than half of failures occurred in restorations with no dentin bonding (n = 14, 51.1%), but the differences found were not significant ($P = .326$).

No significant differences were found regarding sex ($P = .777$).



Figs 3a to 3d Kaplan-Meier survival curves for the event failure of the restoration. **(a)** All restorations; **(b)** onlays; **(c)** two-surface inlays; **(d)** three-surface inlays.

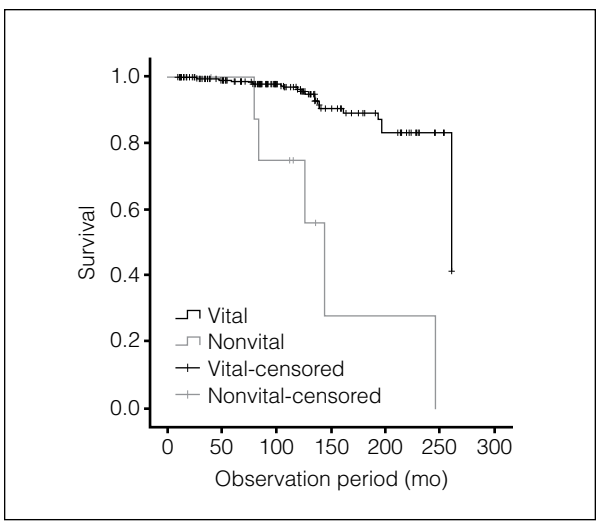


Fig 4 Kaplan-Meier survival curve comparing restorations on vital and nonvital teeth.

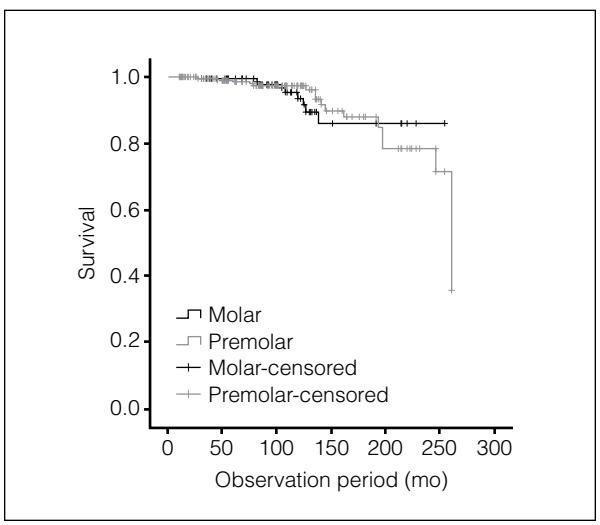


Fig 5 Kaplan-Meier survival curves comparing restorations in molars and premolars.

Discussion

The present retrospective study evaluated the clinical performance of 547 all-ceramic restorations placed in premolar and molar regions. The investigation included a range of ceramic materials placed by two dentists over a long period of time, resulting in little subsequent changes in clinical procedures because of advances in dental materials, eg, the establishment of dentin adhesive systems, to adjust to the latest scientific findings.

After a mean observation period of 80 ± 34 months, 5 failures occurred in the onlay group. The estimated survival probability of all-ceramic onlays over 10 and 12 years was 92.4%. The observation period for onlays was much shorter than that for inlays because the authors started using all-ceramic onlays in posterior teeth as a result of material development at a later point in time. Concerning onlay preparation, the gingival margin was prepared, if possible, in enamel; in cases with deep subgingival preparations, the teeth were restored with cast gold onlays. For this reason, gold and all-ceramic onlays cannot be compared directly because of the different indications at the clinic. Furthermore, longer observation periods must be provided for all-ceramic onlay restorations to gain results with a minimum of 10 years of service to be able to compare them to gold onlay restorations.

After a mean observation period of 111 ± 63 months, 22 failures occurred in the inlay group. The estimated survival probabilities for all-ceramic inlays at 5, 8, 10, 12, 15, 18, and 20 years are 98.9%, 97.3%, 96.8%, 89.6%, 87.2%, 81.5%, and 81.5%, respectively. The results of this study are comparable with the findings of the review analysis and evaluation performed by Land and Hopp,[20] who showed 10-year failure rates of less than 10% for all-ceramic inlay and onlay restorations. Long-term analyses of computer-aided design/computer-assisted manufacture inlays and onlays have now received considerably more attention in the literature, and the results, although concerning mixed restoration types, are more encouraging than 10 years ago. Zimmer et al[21] reported survival rates of 94.7% after 5 years and 85.7% after 10 years, and Reiss[22] reported a survival probability of 84.4% after 18 years.

Nonetheless, cast gold restorations still perform better in posterior teeth, and longer analyses of up to 50 years are available.[23,24] Studer et al[25] reported survival rates for gold inlays and onlays to be 96.1% at 10 years, 87.0% at 20 years, and 73.5% at 30 years.

Many authors state that fractures are the most frequent cause for clinical failure of all-ceramic inlays.[8,10,26,27] Although most failures in the present study were of ceramic origin (fractures, cracks, or chipping), caries was responsible for 8 of 27 failures, followed by ceramic fractures in 7 restorations (see Table 2). These results concur with the findings of the review by Manhart et al.[5] Possible explanations could be inadequate bonding between the porcelain and tooth surface or patient-related factors such as insufficient oral hygiene in the interproximal spaces. However, the results of this study are not in agreement with the study of Krämer and Frankenberger,[26] in which secondary caries did not occur after 8 years of service.

It is established that clinical success with all-ceramic inlays and onlays can only be achieved if the restorations are permanently bonded to the teeth.[2,28,29] Although in the present study more than 50% of all failures occurred in restorations with no dentin bonding, the statistical analysis (log-rank) did not show any significance. However, from the authors' points of view, lack of dentin bonding is a major reason for failure, especially for fracture of the ceramic. Bonding of all-ceramic onlays and inlays is essential to increase the resistance to fracture, as mentioned previously by other study groups.[30,31] The findings might be explained statistically by the uneven distribution of bonding systems and the low number of failures in general.

In addition, the authors expected a significantly higher failure rate for patients with bruxism, especially when taking into account the findings from the clinical evaluation of porcelain laminate veneers at Innsbruck Medical University, in which a 7.7-times greater risk of failure was associated with existing parafunction (bruxism).[32] In the clinical study by Aberg et al,[16] 64% of all fractured inlays occurred in patients with signs of bruxism, but no significant differences were reported. Only speculation can be made as to why bruxism did not influence the failure rate. One reason may be that the presence of the previous findings was too rare or that the preparation type and extension superimposed these parameters. Furthermore, bruxers in this study were compliant with wearing the provided acrylic resin occlusal guards. A strictly obtained canine-guided occlusal concept, as performed for all patients in this study, will reduce occlusal forces during jaw movement as well as the risk of failure. Therefore, meticulous occlusal adjustment has to be performed to avoid premature and balanced contacts.

One possibility to measure and quantify bruxism activity is electronic muscle recording in a laboratory or home environment. The patients in this study did not undergo electronic muscle recording. Parafunction (bruxism) was identified by means of direct questions and visual observation of patient behavior and teeth. At the moment, there is no definitive

method for assessing bruxism clinically that has reasonable diagnostic and technical validity affecting therapeutic decisions and is also cost effective.[33] In the authors' clinic, a lot of time is spent explaining to patients who exhibit bruxism why cast gold restorations are the preferred choice for occluding surfaces where they can be accepted from an esthetic point of view. All patients were informed of the strengths and weaknesses of the all-ceramic material. Thus, during treatment planning discussions, many patients chose the gold alternative. In patients receiving all-ceramic restorations, acrylic resin occlusal guards were provided to protect the definitive all-ceramic restorations during bruxing episodes. Additionally, in patients showing extreme bruxing activity, no adhesive ceramic restorations were performed; the teeth were restored solely with cast gold inlays and onlays. There are not many alternatives to all-ceramic restorations in anterior teeth, which might be one reason for the higher failure in this location. Lavigne et al[15] suggested that research should focus on bruxism behavior rather than bruxism as a disorder. They urged practitioners to undertake systematic studies to determine the dividing line between bruxism as a normal variation of behavior as opposed to a pathogenic behavior that increases the risk of negative consequences. In the future, more clinical studies should examine the clinical impact of bruxism on the oral structures, treatment success, and the factors influencing the decision-making process in dental treatment for prosthodontic restorations.

Higher failure rates for all-ceramic restorations were observed when the restoration was located on nonvital teeth. This is in accordance with the literature, where reduced survival is reported for all-ceramic inlays on nonvital teeth, and the indication is that these restorations should be limited to vital teeth that are not under heavy occlusual loading.[1,22] van Dijken and Hasselrot[34] explained the significantly higher success rate in vital vs nonvital teeth as resulting from the differences in substrates to which hydrophilic primers are applied and hydrophilic dentin in vital teeth vs more sclerotic dentin tissue in endodontically treated teeth.

All-ceramic inlays with three surfaces showed a tendency toward a higher number of failures compared to onlays, but statistical analysis showed no significance ($P = .204$). In this case, the small number of failures might represent a statistical problem, since large differences in the outcome have to be recorded to yield statistically significant differences. This weakens the power of the analysis. Therefore, conclusions must be drawn with caution, but the results still contribute to the general knowledge and are in agreement with the results of Arnelund et al.[35]

Other authors have observed more longevity for inlays on premolars vs those on molars.[27,36,37] Concerning onlays, these results correspond to the study by Naeselius et al,[38] in which the failure rate for molars was 8.1% and no failures occurred at premolars. In the present study, 9 failures were recorded in molars (4 onlays and 5 inlays) and 18 in premolars (1 onlay and 17 inlays). The restorations in premolars survived longer in the first 15 years of observation (see Fig 5), but no statistically significant difference was found between premolars and molars with regard to survival ($P = .913$). However, as Fig 1 demonstrates, the two- and three-surface inlays are distributed in an inhomogenous manner regarding tooth location: only 28 three-surface inlays were constructed in molars compared to 127 in premolars. This might be explained by the experience of the clinicians and the strong indication criteria for all-ceramic restorations and can be attributed to better accessibility in the premolar region, especially in teeth with deeper preparation margins.

Limitations of the present study include that the restorations were performed under university conditions by only two experienced dentists in a select group of patients. Patients had to be free of active gingival and periodontal inflammation prior to ceramic treatment, and focus was placed on careful occlusal adjustment. A more compromised oral environment may have produced different results. In addition, statistical power of the analyses was limited despite the rather large sample size and long observation period, since the total number of failures was low.

Although cast gold restorations still perform slightly better in posterior teeth, it is safe to conclude that properly fabricated all-ceramic restorations in posterior teeth can indeed provide long-term results. In general, the restoration of defects in high-stress posterior teeth requires careful attention to detail in diagnosis, manufacturing, and patient compliance if esthetic all-ceramic restorations are to be considered.

Conclusions

Within the limitations of this study, the following conclusions may be made:

- All-ceramic restorations in posterior teeth provide a predictable and highly successful esthetic restoration.
- The estimated survival probabilities of all-ceramic onlays at 5, 8, 10, and 12 years are 98.9%, 98.1%, 92.4%, and 92.4%, respectively. The estimated survival probabilities of all-ceramic inlays at 5, 8, 10, 12, 15, 18, and 20 years are 98.9%, 97.3%, 96.8%, 89.6%, 87.2%, 81.5%, and 81.5%, respectively.

- The main reason for failure in posterior teeth was secondary caries (29.6%), followed by fracture of the ceramic (25.9%).
- No increased failure rate was associated with bruxism, but an increased failure rate was associated with nonvital abutment teeth.
- No significant differences were found in teeth with prior endodontic treatment compared to those receiving treatment after placing the ceramic restoration.
- Inlays with three surfaces showed a tendency toward a higher number of failures compared to onlays, but the statistical analysis showed no significance ($P = .204$).
- Restorations in premolars survived longer in the first 15 years of service, but no statistical significance was found ($P = .913$) compared to restorations in molars.
- More than half of the failures occurred in restorations with no dentin bonding.

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