©Operative Dentistry, 2009, **34-3**, 263-272

Clinical Research

Clinical Evaluation of Ceramic Inlays Compared to Composite Restorations

RT Lange • P Pfeiffer

Clinical Relevance

Evopress ceramic inlays and Filtek Z250 composite restorations showed no significant difference regarding survival probability at 57 months when used as Class I and II restoratives in premolars and molars. Both materials demonstrated acceptable clinical performance, with a preference for the ceramic inlays.

SUMMARY

This study compared the clinical performance of indirectly manufactured ceramic Evopress inlays with those of directly placed, fine particle hybrid Filtek Z250 composite restorations in posterior teeth.

From January 2000 to October 2003, 109 patients received 264 Evopress (Wegold) ceramic inlays and 68 patients received 145 Filtek Z250 (3M ESPE) composite restorations in a dental office. Two-hundred and fifty ceramic inlays (95%) and 135 composite restorations (93%) were re-examined up to 57 months after placement. Modified USPHS criteria were used for the study. The worst finding of all the assessments was the overall assessment of individual restorations. On the basis of these criteria, 220 (88%) Evopress ceramic inlays were assessed as Alpha at the time of clinical re-examination, 26 (10%) were judged Beta and four ceramic inlays (2%) were rated Delta in the re-examination interval and thus categorized as failures. At the time of re-examination, 91 of the 135 composite restorations (67%) were judged Alpha, 36 restorations (26%) were rated Beta and three restorations (2%) were judged Charlie. Five restorations (4%) were categorized as failures (Delta). In two cases, there were marginal gap formations; there were also two cases of secondary caries after 28 and 35 months, as well as a fracture after 13 months. According to Kaplan and Meier, the survival rate after 57 months was 94% for ceramic inlays and 93% for composite restorations. The log rank test showed no significant differences in the survival curves.

The current study showed that indirectly manufactured Evopress ceramic inlays performed better than direct Filtek Z250 composite restorations in marginal adaptation, color match and

Ralf-Thomas Lange, Dr med, Dr med dent, dentist, private office, Mönchengladbach, Germany

*Peter Pfeiffer, Prof Dr med dent, professor, Department of Prosthetic Dentistry, School of Oral Medicine, University of Cologne, Germany

*Reprint request: Kerpener Str 32, D-50931 Köln, Germany; e-mail: peter.pfeiffer@uni-koeln.de

DOI: 10.2341/08-95

anatomic form. However, with regard to survival probability, there was no significant difference.

INTRODUCTION

Patient demands for tooth-colored restorations in past decades and the need to find alternatives to amalgam were reasons for the increased use of ceramic inlays and resin composite materials for posterior tooth restorations.[1-11] However, long-term studies are needed to compare the clinical behavior of the different materials for posterior restorations.[12-23] The clinical performance of several esthetic tooth-colored materials has been analyzed in various studies. Frankenberger and others evaluated IPS Empress inlays and onlays over a period of six years.[24] Ninety-six ceramic restorations in 34 patients were re-examined using United States Public Health Systems (USPHS) criteria.[39] After one, two, four and six years, the success rates were 96%, 95%, 89% and 67%, respectively. In their second year, a clinical study by Manhart and others compared 47 composite inlays (Tetric) with 24 ceramic inlays (Empress).[25] A re-examination of 78% of the patients was carried out after two years according to the USPHS criteria. One hundred percent of the ceramic and 90% of the composite inlays were categorized as excellent or acceptable (Alpha/Bravo). Manhart and others re-examined ceramic and composite inlays in posterior teeth after three years.[26] Forty-seven composite inlays (Tetric, Blend-a-lux and Pertac) were compared to 84 ceramic inlays (Empress). Re-examination of 81.7% of the inlays could be carried out after three years using USPHS criteria. One hundred percent of the ceramic inlays and 89% of the composite inlays were assessed as excellent or acceptable (Alpha/Bravo). In their re-examination of IPS Empress ceramic restorations in molars, El-Mowafy and others found a survival rate of 96% after 4.5 years and 91% after seven years.[27]

Posselt and others evaluated a survival rate of 95.5% after nine years for 794 patients with 2,328 CAD/CAM ceramic inlays (Cerec).[28] The most frequent reasons for failure were tooth loss due to extraction (22.9%) and ceramic fractures (17.1%). Otto and others examined 187 Cerec inlays and onlays (Cerec 1 CAD/CAM procedure and Vita MK I feldspar ceramic) in private practices over a period of 17 years.[15] According to the USPHS criteria, the success rate for Cerec ceramic inlays and onlays was 88.7% after 17 years. Reiss and others carried out a long-term clinical study of Cerec restorations in a private practice.[29] Re-examinations were carried out on 299 patients with 1,010 ceramic restorations over a period of 9-12 years after placement. The survival rate after 10 years was 90%; after 11.8 years, it was 84.9%. In their study, Sjögren and others carried out an evaluation of Class II Cerec inlays after 10 years.[30] They examined 66 Class II CAD/CAM ceramic inlays in 27 patients. Ninety-three percent (25) of the patients with 61 inlays (92%) were examined in accordance with the USPHS criteria. Eighty-nine percent of the 61 inlays were clinically successful. Eleven percent of the inlays had to be replaced. Opdam and others evaluated the five-year survival rate of composite restorations in posterior teeth placed by students.[31] Re-examination of 560 of the 703 Class I and II restorations could be carried out on 382 patients. The survival rate was 87% after five years, with an annual failure rate of 2.8%. The most frequent failures of the 94 restorations were fractures (22), secondary caries (19), endodontic treatments (12), marginal gaps (8) and loss of proximal contact points (9). Ilda and others compared Class II ceramic inlay restorations (Cerec) with direct composite restorations with regard to marginal gap.[32] The direct composite restorations exhibited a higher occurrence of marginal gaps and micro-fractures in the marginal area than Cerec inlay restorations. Mackert and others compared several retrospective studies and summarized the annual failure rates were as follows: 0-7% in amalgam restorations, 0-9% in direct composite restorations, 1.4%-14.4% in glass ionomer restorations, 0-5.9% in gold inlays and onlays and 0-11.8% in ceramic or composite inlays.[33]

The current study compared the clinical performance of ceramic Evopress inlays with directly placed fine particle hybrid Filtek Z250 composite restorations based on the hypothesis that indirectly manufactured ceramic inlays reveal better clinical results than direct composite restorations.

METHODS AND MATERIALS

During the period January 2000 to October 2003, 109 patients received 264 Evopress ceramic inlays (Wegold, Wendelstein, Germany) in posterior teeth (premolars, molars) in a private practice dental office in Germany. Patients with bruxism were excluded. The mean age of the patients was 35 years (+/-12 years). Women (n=59) with 144 restorations were more frequently represented than men (n=50), who received 120 inlays. In the years from 2000 to 2002, the number of ceramic restorations that were placed increased with a rate of approximately 18% per year (Tables 1 and 2). In 2000 and 2003, the number of ceramic restorations placed was equally high.

During the period January 2000 to October 2003, another 68 patients received 145 composite restorations (Filtek Z250, 3M ESPE, Seefeld, Germany) in posterior teeth (premolars, molars, Table 2). Patients with bruxism were excluded. The mean age of the patients was 32 years (+/- 16 years). Women (n=32) with 80 composite restorations were more frequently represented than men (n=36), who received 65 restorations. In 2000 and 2003, the number of composite restorations that were placed was equally high (Table 3).

Table 1: *Modified USPHS (United States Public Health Systems) Criteria Used for the Clinical Evaluation of the Ceramic Inlays and Composite Restorations*

Marginal Adaptation	
Alpha	Restoration closely adapted to the tooth. No crevice visible. No explorer catch at the margins or there was a catch in one direction.
Bravo	Explorer catch. No visible evidence of a crevice into which the explorer could penetrate. No dentin or base visible.
Charlie	Explorer penetrates into a crevice that is of a depth that exposes dentin or base.
Delta	The restoration is loose, fractured or lost.
Anatomic Form	
Alpha	Restorations continuous with existing anatomic form.
Bravo	Restorations discontinuous with existing anatomic form but missing material not sufficient to expose dentin base.
Charlie	Sufficient material lost to expose dentin or base.
Secondary Caries	
Alpha	No visual evidence of dark, deep discoloration adjacent to the restoration.
Bravo	Visual evidence of dark, deep discoloration adjacent to the restoration.
Color Match	
Alpha	Restoration matches adjacent tooth structure in color and translucency.
Bravo	Mismatch is within an acceptable range of tooth color and translucency.
Charlie	Mismatch is outside the acceptable range.
Surface Roughness	
Alpha	Surface of restoration is smooth.
Bravo	Surface of restoration is slightly rough or pitted but can be refinished.
Charlie	Surface deeply pitted, irregular grooves and cannot be refinished.
Marginal Discoloration	
Alpha	No discoloration between restoration and adjacent tooth structure.
Bravo	Discoloration between restoration and adjacent tooth structure without penetration in the pulpal direction.
Charlie	Discoloration between the restoration and adjacent tooth structure with penetration in the pulpal direction.

Ceramic Inlay Procedure

All cavities received the common preparation for ceramic inlay restoration.[34-35] To ensure sufficient stability for inlay restorations and to prevent ceramic fractures, a preparation depth of at least 1.5 mm was performed.[34-36] A calcium hydroxide base (Kerr Life, Kerr, Rastatt, Germany) was used as indirect pulp-capping material for deeper cavities. A glass ionomer lining was placed on the dentin (Ketac Bond, 3M ESPE). The impression was taken with a silicone impression material (correction impression, Silaplast Futur, Detax, Ettlingen, Germany) followed by a silicone low-viscous tooth impression material (Xantopren L, Heraeus Kulzer, Wehrheim, Germany). The temporary inlays were made from resin composite (Filtek Z250, 3M ESPE) and bonded with a temporary zinc oxide eugenol-free cement (Temp Bond NE, Kerr).

The ceramic Evopress inlay restorations were all manufactured in the same dental laboratory.

The glass ceramic material Evopress was processed using hot press procedures. Ceramic cylinders of different transparencies and Vita shades were available. The main inlay components were SiO_2 (80%) and Al_2O_3.

Finally, the Evopress ceramic inlay was acid-etched for 60 seconds with 5% hydrofluoric acid (Vita Ceramics Etch, Vita, Bad Säckingen, Germany). The acid-etched ceramic surface was then sprayed and the restoration was delivered to the private practice.

The cotton roll isolation technique was used for most patients. A rubber dam (Hygienic Dental Dam, Coltène Whaledent, Langenau, Germany) was applied to patients with strong salivation. To ensure micromechanical bonding of the ceramic inlays, the enamel was acid-etched for 30 seconds with 37% phosphoric acid (Scotchbond Etchant Gel, 3M ESPE). A thin layer of the bonding material (maleic acid, hydrophilic methacrylates, polyfunctional monomers; Solobond Plus, VoCo, Cuxhaven, Germany) was applied to the cavity utilizing a fine sable brush, then the surplus liquid was carefully blown away. According to the manufacturer's instructions, Solobond Plus can be used either as a self-conditioning primer under modification of the smear layer or in the total-etch technique with conditioning by concentrated phosphoric acid. Both techniques create an elastic hybrid layer as a factor of permanent adhesion. By means of the self-conditioning primer, the dentin is partially demineralized without causing destruction of the dentin structures or collapsing of the collagen net. A silane coupling agent (Bifix DC Ceramic Bond, VoCo) was applied to the internal inlay surface for 60 seconds and air-dried. Before inser-

Table 2: *Examination of the marginal adaptation, anatomic form, color match, surface roughness of restorations, discoloration on the cavity margin (n=246) and the overall assessment of ceramic restorations according to USPHS criteria (n=250) according to the year of placement.*

	2000 n=50	2001 n=59	2002 n=80	2003 N=57
Marginal Adaptation	a	b		ab
Alpha	42	51	78	57
Bravo	8	8	2	0
Charlie	0	0	0	0
Delta	0	0	0	0
Anatomic Form				
Alpha	48	58	79	57
Bravo	2	1	1	0
Charlie	0	0	0	0
Secondary Caries				
Alpha	0	0	0	0
Bravo	0	0	0	0
Color Match				
Alpha	45	55	77	57
Bravo	5	4	3	0
Charlie	0	0	0	0
Surface Roughness				
Alpha	48	59	80	57
Bravo	2	0	0	0
Marginal Discoloration	a	b	c	abc
Alpha	40	49	74	57
Bravo	10	10	6	0
Charlie	0	0	0	0
	n=52	**n=59**	**n=82**	**n=57**
Overall Assessment	a	b	b	ab
Alpha	40	49	74	57
Bravo	10	10	6	0
Charlie	0	0	0	0
Delta	2	0	2	0

Groups with the same superscripted letters in a row are significantly different (p≤0.05).

tion, the internal inlay surface and the cavity walls were coated with a dual polymerizing resin composite (Bifix, VoCo), then the inlay was placed into the cavity. The surplus was removed using a dental probe and dental floss (Paro Glide Tape, Profimed, Stephanskirchen, Germany), and, if necessary, a scaler. Resin composite was light polymerized for 60-80 seconds (light intensity 750 W/cm^2, Polofil Lux lamp, VoCo). Finishing of the definitively set inlay was carried out using fine-grit diamonds (No 862, ISO 012, Brasseler, Lemgo, Germany), rubber points (No 9547, Brasseler), polishing wheels (Super-Snap, Shofu, Ratingen, Germany) and polishing strips (Super-Snap-Polishing strip, Shofu). The tooth was subsequently coated with a fluoride gel (Elmex-Gelee, Gaba, Lörrach, Germany) and foam material pellets (Pele Tim No 3, VoCo). Occlusion and articulation assessment was carried out using occlusion paper (occlusion paper blue, Bausch, Nashua, NH, USA).

Procedure for Composite Restorations

The cavities were prepared using low-speed burs (H1, Brasseler) to remove carious tissue and carbide burs (H 32, Brasseler) to remove old restorations. The preparation was performed by creating resistance and retention forms. Contrary to the preparation of ceramic inlays, undercuts were created to produce additional mechanical retention aside from micromechanical retention via acid etching. In the supragingival area, the cavity cavosurface margins (0.5 mm-1 mm) were beveled with a 45–60 degree angle. All the cavities were cleaned with H_2O_2. Deeper cavities were covered with calcium hydroxide (Kerr Life, Kerr). Subsequently, the cotton roll isolation technique was used for most patients. A rubber dam (Hygienic Dental Dam, Coltène Whaledent) was applied to patients with strong salivation.

All the enamel and cavosurface margins were acid-etched with 37.5% phosphoric acid (Scotchbond Etchant Gel, 3M ESPE) for 15 seconds, washed and dried by air flow. A bonding agent (Prime Bond NT, Dentsply, Konstanz, Germany) was applied to the cavity utilizing a fine sable brush. According to the manufacturer's instructions, Prime Bond NT can be used either as a self-priming dental adhesive without dentin etching or in the total-etch technique with conditioning of the enamel and dentin by concentrated phosphoric acid. For correspondence with the ceramic inlay procedure, the enamel-etch technique, rather than the total-etch technique, was preferred.

The bonding agent was left in the cavity for 30 seconds, then air-dried and light-polymerized for 20 seconds with the polymerization lamp (light intensity 750 W/cm^2, Polofil Lux lamp, VoCo). The resin composite

(Filtek Z250, 3M ESPE) was placed and light-polymerized according to an incremental technique similar to the oblique technique.[37-38] The resin composite was not placed into the cavity all at once; instead, it was inserted in layers, and each layer was polymerized separately. The aim was to keep shrinkage of the composite material as low as possible. Resin composite was polymerized in maximum layers of 2 mm for 20 seconds using a Polofil Lux light curing unit (VoCo).

Finishing of the restoration was carried out by adapting occlusion and articulation using fine-grit diamonds (No 314, ISO 012, Brasseler). Finally, the composite restoration was polished using rubber points (No 9608 and No 9618, Brasseler), polishing wheels (Super-Snap, Shofu) and polishing strips (Super-Snap-Polishing strip, Shofu).

The ceramic inlays and resin composite restorations were all placed by the same operator, who was not involved in the re-examination process.

Table 3: *Examination of the marginal adaptation, anatomic form, color match, surface roughness of restorations, discoloration on the cavity margin (n=130) and the overall assessment of composite restorations according to USPHS criteria (n=135), according to the year of placement.*

	2000 n=34	2001 n=33	2002 n=29	2003 n=34
Marginal Adaptation	a	b		ab
Alpha	24	26	25	34
Bravo	9	6	3	0
Charlie	1	1	1	0
Delta	0	0	0	0
Anatomic Form				
Alpha	25	28	25	34
Bravo	9	5	4	0
Charlie	0	0	0	0
Secondary Caries				
Alpha	0	0	0	0
Bravo	0	0	0	0
Color Match				
Alpha	24	27	22	32
Bravo	10	6	7	2
Charlie	0	0	0	0
Surface Roughness				
Alpha	30	32	29	34
Bravo	4	1	0	0
Marginal Discoloration	a	b	c	abc
Alpha	21	23	20	30
Bravo	13	10	9	4
Charlie	0	0	0	0
	n=36	**n=35**	**n=30**	**n=34**
Overall Assessment	**a**	**b**	**b**	**ab**
Alpha	20	22	19	30
Bravo	13	10	9	4
Charlie	1	1	1	0
Delta	2	2	1	0

Groups with the same superscripted letters in a row are significantly different (p≤0.05).

Data Recording and Criteria for Re-examination

Patient selection was carried out by searching through patient registers from 2001 to 2003. A researcher (RTL) who had no previous contact with the patients conducted all of the selection procedures. All of the patients who received ceramic inlays or composite restorations during these years were selected from the patient records, contacted by telephone or in writing and invited to follow-up examinations, which were to be carried out between April 2004 and March 2005. The re-examination of the ceramic inlays and composite restorations was carried out according to clinically approved USPHS-criteria.[22,39] The definition of the criteria (marginal adaptation, anatomic form, color match of the restoration, presence of secondary caries, surface roughness and marginal discoloration between restoration and tooth structure) used is given in Table 1. Re-examination was carried out using a dental mirror, tweezers and a sharp probe (New Friling 6 XL, Aesculap, Munich, Germany). The decision for the overall assessment of a restoration was the worst result of the assessment.

Additionally, pulp vitality was tested for all restored teeth.

Statistical Analysis

Descriptive statistics were used to describe the frequency distributions of the evaluated criteria. The chi-square test was performed to determine differences in the clinical behavior (USPHS criteria) of the restorations, depending on the year of placement ($p<0.05$). The survival rates of ceramic inlays and composite restorations were calculated by the Kaplan-Meier estimator (95% level of confidence).[40] The logrank test was

used to compare the survival distributions of the ceramic inlays and the composite restorations ($p<0.05$).

RESULTS

In total, 161 patients with 385 restorations could be re-examined from April 2004 to March 2005. One hundred patients with 250 ceramic inlay restorations and 61 patients with 135 composite restorations agreed to participate in the study. Follow-up examinations could not be carried out on 9% (n=9) of patients with ceramic inlay restorations and 10.3% (n=7) of patients with composite restorations. Fourteen patients could not be contacted in writing or by telephone. Two patients disagreed to participate in the study. The patients in the ceramic restoration group, who were included in the re-examination, revealed a mean age of 35.7 years (+/- 11.7 years); for the patient group with composite restorations, a mean age of 33.3 years (+/- 16.5 years) was calculated.

Re-examinations (ratio of 1.22:1 for women to men) could not be carried out on five female patients with six ceramic inlay restorations and on four male patients with eight ceramic inlay restorations. Most of the ceramic restorations were placed in Class II occlusal-distal (OD, 30.8%) and mesial-occlusal-distal (MOD, 25.6%) cavities. Mesial-occlusal cavities were found in 20.8%, occlusal cavities in 14.8%. Other cavity extensions were rare (≤2% per group, overall 8%).

Of the 68 patients who received composite restorations, seven male patients with 10 restorations did not attend the re-examination. Of the 61 patients (ratio of 1.35:1 for women to men) with 135 composite restorations, the majority of the composite restorations were placed in Class I occlusal (O, 24.4%) and Class II occlusal-distal (OD, 27.4%) and mesial-occlusal (MO, 17%) cavities. Mesial-occlusal-distal cavities were found in 12.6% of patients, while other cavity extensions were rare (≤3.7% per group, overall 18.6%).

Repaired restorations (except after root canal filling) and fractured restorations, which had to be replaced, were classified as failures.

Four failures were recorded for the 250 ceramic restorations during the observation time. After 13 months, one ceramic inlay in a molar showed a marginal gap with exposed dentin. In one patient, ceramic restorations in two premolars (24 OD, 25 MOD) fractured after 11 months. A ceramic fracture in a molar occurred after 17 months. Accordingly, the total number of ceramic inlays that could be re-examined deteriorated to 246 ceramic restorations.

At the time of restoration with Evopress ceramic inlays, all teeth exhibited a positive response to pulp vitality testing. Of the 250 teeth, three had to undergo root canal treatment (two molars after two and eight months and a premolar after three months).

Five failures were recorded for the 135 composite restorations during the observation time. Two composite restorations exposed dentin at the cavity cavosurface angles after four and 17 months, respectively. In two molars, secondary caries occurred after 28 and 35 months, respectively. The fracture of the lingual cusp of a premolar was detected after 13 months. Accordingly, the total number of composite restorations that could be re-examined deteriorated to 130 restorations due to the reported failures during the observation time.

All teeth that received Filtec Z250 composite restorations showed a positive responsiveness in thermal/electric pulp tests at the time of composite placement. Four of the 135 re-examined teeth obtained root canal treatment (one molar after 47 months, two molars after six months and one premolar after 23 months) due to irreversible pulpitis.

The results of the clinical re-examination of the 246 ceramic inlays and 130 composite restorations using modified USPHS criteria are summarized in Tables 2 and 3.

Marginal Adaptation

Ninety-three percent (228) of the ceramic inlays received Alpha ratings, with the restorations closely adapted to the teeth (Table 2). Seven percent (18) of the ceramic inlays exhibited smaller irregularities without visible dentin or glass ionomer lining exposed (Bravo). Clinical examination revealed no ceramic fracture (Table 2).

Compared with these results, 84% (109) of the composite restorations were rated Alpha and 14% (18) obtained a Bravo rating (Table 3). In 2% (3) of the composite restorations, there were irregularities at the margin of the restoration with dentin exposed (Charlie).

Marginal adaptation of ceramic inlays and composite restorations with a longer observation period (placed in 2000 and 2001) was significantly worse than those placed in 2003 ($p<0.05$, Tables 2 and 3).

Anatomic Form

Ninety-eight percent (242) of the ceramic inlays showed intact anatomic surface morphology continuous with existing anatomic tooth form and were therefore rated Alpha. Two percent (4) of the restorations obtained a Bravo rating (Table 2). There were no statistically significant differences for the USPHS ratings of the anatomic form of ceramic restorations regardless of the year of placement ($p>0.05$, Table 2).

Eighty-six percent (112) of the composite restorations received an Alpha rating (Table 3). Fourteen percent (18) of the restorations were discontinuous, with existing anatomic form with missing material not sufficient to expose the dentin base (Bravo). Significant differences in the anatomic form were obtained for composite

restorations placed in 2000 and 2001 compared with restorations placed in 2003 ($p<0.05$, Table 3).

The ceramic and composite restorations classified as Bravo were exclusively restorations in molars.

Secondary Caries

At the time of re-examination, there was no secondary caries in either ceramic or composite restored teeth (Tables 2 and 3).

Color Match

In assessing the color change between the restoration and tooth, as well as the surface translucency, 95% (234) of the ceramic inlays were rated Alpha (Table 2). Five percent (12) of the restorations were categorized as Bravo. USPHS ratings of the color match of ceramic restorations were not significantly different regardless of the year of placement ($p>0.05$, Table 2).

Eighty-one percent (105) of the composite restorations matched adjacent tooth structure in color and translucency and obtained an Alpha rating. Nineteen percent (25) of the restorations were rated Bravo (Table 3). Color match of composite restorations placed in 2003 was significantly different from those placed in 2000 ($p<0.05$, Table 3).

Surface Roughness

Upon assessment of the surface roughness, there was no evident difference between ceramic and composite restorations. Ninety-nine percent (244) of the ceramic inlays (Table 2) and 96% (125) of the composite restorations received an Alpha rating (Table 3). Bravo ratings were found in 1% (2) of the ceramic inlays and in 4% (5) of the composite restorations. There were no significant differences for the USPHS ratings of the surface roughness of ceramic inlays regardless of the year of placement ($p>0.05$, Table 2). The surface roughness of composite restorations placed in 2000 was significantly different from ratings of the restorations placed in 2002 and 2003 ($p<0.05$, Table 3).

Marginal Discoloration

The examination of discoloration on the cavity margin of ceramic inlays showed no discoloration between the restoration and adjacent tooth structure for 89% (220) of the ceramic inlays (Alpha, Table 2). Eleven percent (26) of the restorations showed discoloration without penetration in the pulpal direction (Beta). Marginal discoloration of ceramic inlays placed in 2003 showed significant differences compared with restorations placed in 2000, 2001 and 2002 ($p<0.05$, Table 2).

Seventy-two percent (94) of the composite restorations were rated Alpha and 28% (36) received a Beta rating (Table 3). Marginal discoloration of composite restorations placed in 2003 was significantly different from those placed in 2000 ($p<0.05$, Table 3).

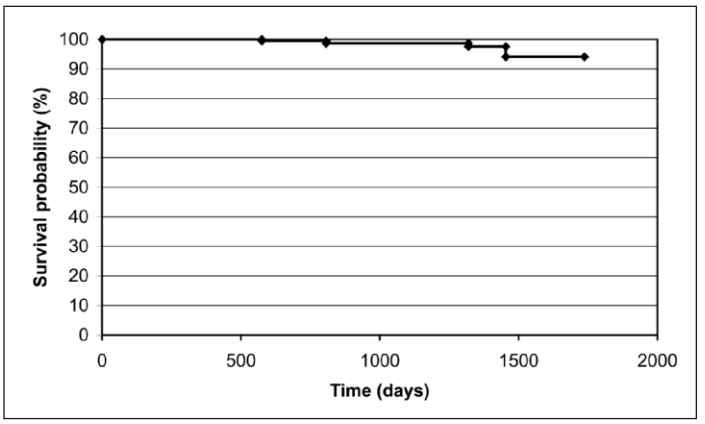

Figure 1. *Survival probability of ceramic inlays according to Kaplan-Meier.*

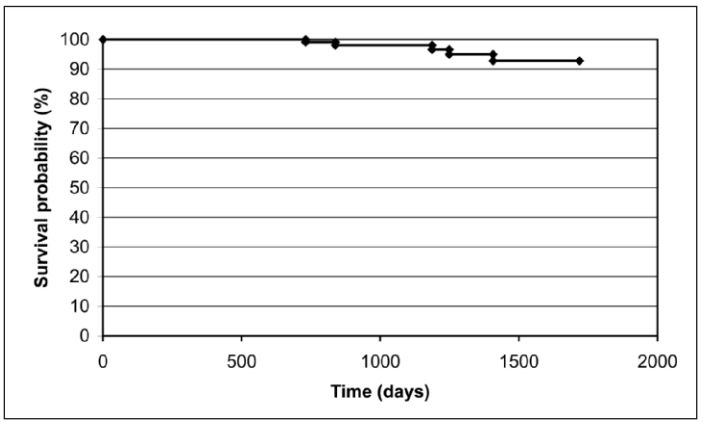

Figure 2. *Survival probability of composite restorations according to Kaplan-Meier.*

The overall assessment of ceramic and composite restorations, including failures (repair, fracture of the restoration) during the observation period is displayed in Tables 2 and 3. Thus, 88% (220) of the Evopress ceramic inlays and 67% (91) of Filtek Z250 composite restorations were rated Alpha. Four ceramic inlays (2%) and five composite restorations (4%) were categorized as failures during the observation period. Overall assessment of the ceramic inlays and composite restorations placed in 2003 showed significant differences compared with restorations placed in 2000, 2001 and 2002 ($p<0.05$, Tables 2 and 3).

Survival Probability

The Evopress ceramic inlays had been in place for a mean of 984 days (± 385, interval 337-1,737 days). The average wearing time of the composite inlays was 1,093 days (± 417, interval 340-1,718 days). The survival probability at the end of the observation period was 94% for ceramic inlays (Figure 1) and 93% for composite restorations (Figure 2). The log rank test showed no significant differences between the groups of ceramic and composite restorations ($p=0.3901$).

DISCUSSION

In many *in vivo* studies, USPHS criteria were used for the clinical evaluation of tooth-colored restorations in posterior teeth.[22,24,34,39] To ensure comparability of the results of the current study with other studies, in this study, ceramic inlays and composite restorations were assessed using USPHS criteria.

The Evopress ceramic inlays evaluated in the current study had been in place for a mean of 33 months. The average wear time of the composite inlays was 36 months, with a maximum observation period of four years and nine months. Some clinical studies using USPHS criteria had shorter observation periods,[3,20,25] while others showed comparable intervals[1,21] or longer observation periods.[2,14-15,22] Many of these studies have proven that ceramic material is an alternative to other materials, such as resin composite, gold and amalgam for Class I and II restorations, even for extensive defects.[2,9-10,23,31,33] The rate of loss of amalgam restorations was calculated between 0-7%, for composite inlays between 0-9%, for gold inlays up to 5.9% and for ceramic restorations between 0-11.8%. In the current study, the rate of loss for composite inlays was 4%, and it was 2% for ceramic inlays. The number of failures in the ceramic inlay and resin composite groups was too small to evaluate the probability of survival, depending on the cavity type (Class I, II) or the cavity size (one-surface, two-surfaces, multi-surface restorations). In their study, Krämer and others used the same re-examination interval and the same re-examination criteria.[3] They found a failure rate of 7% for the tested ceramic inlays (IPS Empress). The Evopress inlays examined in the current study showed a lower failure rate than the IPS Empress inlays. Erpenstein and others evaluated 2,071 gold inlays over a period of up to 30 years and found a survival rate of 97% after 10 years and 73% after 25 years.[12] Reiss and others obtained similar results in their long-term study with CAD/CAM-manufactured ceramic inlays.[29] After 10 years of wear, 90% of the restorations were assessed as a clinical success. Posselt and others confirmed these findings for 2,328 CAD/CAM-manufactured ceramic restorations. They found a survival probability of 95.5% after nine years.[28]

Manhart and others compared conventionally-manufactured indirect ceramic inlays with composite restorations.[25] Composite restorations obtained a survival rate of 90%, and ceramic inlays revealed a survival probability of 100% after a period of two years. In the current study, this was confirmed for Evopress ceramic restorations with a two-year survival rate of 99.5%; whereas, composite restorations exhibited a higher two-year survival probability (99.1%) than in the study by Manhart and others.[25]

Three ceramic restorations in the current study were lost due to fractures, two in the premolar region (OD and MOD restorations) and one in the molar region (MO restoration). This corresponded to 75% of the overall failure rate. Repaired restorations (except after root canal filling) and fractured restorations that had to be replaced were classified as failures. This approach was independent of whether the failure was caused by the material, the operator or the patient.

Other studies of ceramic restorations found fracture rates as high as 60% of the overall failures.[3,25,27,29] In composite restorations in the current study, there was one fracture after 13 months (MOD restoration). Manhart and others stated that a higher rate of ceramic fractures in molars than in premolars depended on the size of the defect.[13,18,29] Dalpino and others proved that indirect manufactured ceramic restorations in larger cavities had a greater ability to withstand fractures (1.77 kN) than directly manufactured Filtek Z250 restorations (1.45 kN).[35]

Additional loss was caused by improper marginal adaptation. In the current study, 93% of the ceramic inlays were rated Alpha, with no detectable irregularities on the margin. In comparison, in 84% of the composite restorations, a similar result was found. It remains to be stated that 2% of the composite restorations showed irregularities on the cavity margin with dentin exposed (Charlie), whereas no Charlie rating was assessed for the ceramic inlays. Dalpino and others revealed that ceramic inlays in extensive MOD cavities showed significantly fewer marginal gaps after thermal aging and mechanical loading than composite restorations.[35] Iida and others compared the marginal adaptation of Class II direct composite restorations with Cerec inlays.[32] In direct composite restorations, more marginal gaps at the occlusal enamel margins were noted than in the Cerec inlay group. The current clinical study confirmed these findings, with a 9% higher accurate marginal adaptation (Alpha) of the ceramic inlays than of the direct composite restorations.

Ozturk and others attributed the problems of crevice and the occurrence of marginal gaps to weakening of the adhesive composite.[19] In a prospective controlled study, Krämer and others found marginal gap formation in 7% of the ceramic inlays (IPS Empress), independent of the luting composite.[3] In the current study, similar results were obtained for Evopress ceramic inlays.

Evopress inlays were rated Alpha regarding anatomic form in 98% of the restorations, for color match in 95% and for surface roughness in 99%. Sjörgen and others assessed Empress ceramic restorations and found smaller Alpha ratings of 74% for anatomic form, 86% for color match and 90% for surface roughness.[4] Santos and others obtained similar results for IPS Empress ceramic inlays after two years (Alpha 95% color match, 97% surface roughness), as in the current study.[20,36]

The rising number of CAD/CAM restorations in recent years requires a comparison of the survival rates with conventional, laboratory manufactured, indirect ceramic inlay restorations. Various studies have confirmed the long-term success of CAD/CAM restorations.[17,19,29,31,34] In many studies, survival probability was calculated from 84% to 96%. In the current study, the survival probability of Evopress ceramic inlays was 98% and 96.3% for Filtek Z250 composite restorations. Considering comparable wearing times of the restorations, Evopress ceramic inlays and Filtek Z250 composite restorations were in the range of the survival rates of the CAD/CAM ceramic and conventional indirect manufactured ceramic restorations.[7-8,15]

It would be important to conduct further studies on the clinical evaluation of ceramic inlays and composite restorations, considering a multicenter and multi-operator experimental design, in order to provide data of stronger power of interference and to determine the operator influence on the clinical performance of posterior ceramic and composite restorations.[22] However, a study with a single operator is a commonly used method in clinical evaluations in dentistry. It allows for a more controlled comparison of materials and techniques. Hence, the current study was designed to reduce confounding variables, such as operator and working environment.[22]

Based on the results, the hypothesis that indirectly manufactured ceramic inlays (Evopress) reveal better clinical results than direct composite restorations (Filtec Z250) is accepted for marginal adaptation, color match and anatomic form and can be rejected for the survival probability.

CONCLUSIONS

Considering the results, the following can be concluded:

1) Survival probability of Evopress ceramic inlays was 94% and 93% for Filtek composite restorations up to 57 months of clinical service. The survival curve of ceramic inlays was not significantly different from the survival curve of composite restorations;
2) Evopress ceramic inlays obtained higher (but not statisticallyy significant) Alpha ratings in marginal adaptation, anatomic form, color match of the restoration and marginal discoloration between restoration and tooth structure compared to Filtek composite restorations. Ratings of the presence of secondary caries and surface roughness were similar for both materials.

(Received 21 July 2008)

References

1. Fradeani M, Aquilano A & Bassein L (1997) Longitudinal study of pressed glass-ceramic inlays for four and a half year *The Journal of Prosthetic Dentistry* **78(4)** 346-353.
2. Roulet JF (1997) Longevity of glass ceramic inlays and amalgam—results up to 6 years *Clinical Oral Investigations* **1(1)** 40-46.
3. Krämer N, Frankenberger R, Pelka M & Petschelt A (1999) IPS Empress inlays and onlays after four-years: A clinical study *Journal of Dentistry* **27(5)** 325-331.
4. Sjörgen G, Lantto R, Granberg A, Sundstrom BO & Tillberg A (1999) Clinical examination of leucite-reinforced glass-ceramic crowns (Empress) in general practice: A retrospective study *The International Journal of Prosthodontics* **12(2)** 122-128.
5. Sturdevant JR, Bayne SC & Heymann HO (1999) Margin gap size of ceramic inlays using second-generation CAD/CAM equipment *Journal of Esthetic Dentistry* **11(4)** 206-214.
6. Addi S, Hedayati-Khams A, Poya A & Sjögren G (2002) Interface gap size of manually and CAD/CAM-manufactured ceramic inlays/onlays *in vitro Journal of Dentistry* **30(1)** 53-58.
7. Mörmann WH & Bindl A (2002) All-ceramic, chairside computer-aided design/computer-aided machining restorations *Dental Clinics of North America* **46(2)** 405-426.
8. Kurbad A (2002) Clinical aspects of all-ceramic CAD/CAM restorations *International Journal of Computerized Dentistry* **5(2-3)** 183-197.
9. Brackett WW, Browning WD, Brackett MG, Callan RS & Blalock JS (2007) Effect of restoration size on the clinical performance of posterior "packable" resin composites over 18 months *Operative Dentistry* **32(3)** 212-216.
10. Perdigão J, Dutra-Correa M, Castilhos N, Carmo AR, Anauate-Netto C, Cordeiro HJ, Amore R & Lewgoy HR (2007) One-year clinical performance of self-etch adhesives in posterior restorations *American Journal of Dentistry* **20(2)** 125-133.
11. Bortolotto T, Onisor I & Krejci I (2007) Proximal direct composite restorations and chairside CAD/CAM inlays: Marginal adaptation of a two-step self-etch adhesive with and without selective enamel conditioning *Clinical Oral Investigations* **11(1)** 35-43.
12. Erpenstein H, Kerschbaum T & Halfin T (2001) Long-term survival of cast-gold inlays in a specialized dental practice *Clinical Oral Investigations* **5(3)** 162-166.
13. Kunzelmann KH, Jelen B, Mehl A & Hickel R (2001) Wear evaluation of MZ 100 compared to ceramic CAD/CAM materials *International Journal of Computerized Dentistry* **4(3)** 171-184.
14. Blatz MB (2004) Long-term clinical success of all-ceramic posterior restorations *Quintessence International* **33(6)** 415-426.
15. Otto T & Schneider D (2008) Long-term clinical results of chairside Cerec CAD/CAM inlays and onlays: A case series *The International Journal of Prosthodontics* **21(1)** 53-59.
16. Hayashi M, Wilson NH, Yeung CA & Worthington HV (2003) Systematic review of ceramic inlays *Clinical Oral Investigations* **7(1)** 8-19.

17. Mota CS, Demarco FF, Camacho GB & Powers JM (2003) Microleakage in ceramic inlays luted with different resin cements *The Journal of Adhesive Dentistry* **5(1)** 63-70.

18. Arnelund CF, Johansson A, Ericson M, Häger P & Arvidson Fryberg K (2004) Five-year evaluation of two resin-retained ceramic systems: A retrospective study in a general practice setting *The International Journal of Prosthodontics* **17(3)** 302-306.

19. Ozturk N, Ozturk B & Aykent F (2004) Microleakage of different cementation techniques in Class V ceramic inlays *Journal of Oral Rehabilitation* **31(12)** 1192-1196.

20. Santos C, Mondelli R, Lauris J & Navarro M (2004) Clinical evaluation of ceramic inlays and onlays fabricated with two systems: Two-year clinical follow up *Operative Dentistry* **29(2)** 123-130.

21. Krämer N, Ebert J, Petschelt A & Frankenberger R (2006) Ceramic inlays bonded with two adhesives after 4 years *Dental Materials* **22(1)** 13-21.

22. da Rosa Rodolpho PA, Cenci MS, Donassollo TA, Loguercio AD & Demarco FF (2006) A clinical evaluation of posterior composite restorations: 17-year findings *Journal of Dentistry* **34(7)** 427-435.

23. Akimoto N, Takamizu M & Momoi Y (2007) 10-year clinical evaluation of a self-etching adhesive system *Operative Dentistry* **32(1)** 3-10.

24. Frankenberger R, Petschelt A & Krämer N (2000) Leucite-reinforced glass ceramic inlays and onlays after six years: Clinical behavior *Operative Dentistry* **25(6)** 459-465.

25. Manhart J, Scheibenbogen-Fuchsbrenner A, Chen HY & Hickel R (2000) A 2-year clinical study of composite and ceramic inlays *Clinical Oral Investigations* **4(4)** 192-198.

26. Manhart J, Chen HY, Neuerer P, Scheibenbogen-Fuchsbrunner A & Hickel R (2001) Three-year clinical evaluation of composite and ceramic inlays *American Journal of Dentistry* **14(2)** 95-99.

27. El-Mowafy O & Brochu JF (2002) Longevity and clinical performance of IPS-Empress ceramic restorations—a literature review *Journal of Canadian Dental Association* **68(4)** 233-237.

28. Posselt A & Kerschbaum T (2003) Longevity of 2328 chairside Cerec inlays and onlays *International Journal of Computerized Dentistry* **6(3)** 231-248.

29. Reiss B & Walther W (2000) Clinical long-term results and 10-year Kaplan-Meier analysis of Cerec restorations *International Journal of Computerized Dentistry* **3(1)** 9-23.

30. Sjögren G, Molin M & van Dijken JW (2004) A 10-year prospective evaluation of CAD/CAM-manufactured (Cerec) ceramic inlays cemented with a chemically cured or dual-cured resin composite *The International Journal of Prosthodontics* **17(2)** 241-246.

31. Opdam NJM, Loomans BAC, Roeters FJM & Bronkhorst EM (2004) Five-year clinical performance of posterior resin composite restorations placed by dental students *Journal of Dentistry* **32(5)** 379-383.

32. Iida K, Inokoshi S & Kurosaki N (2003) Interfacial gaps following ceramic inlay cementation vs direct composites *Operative Dentistry* **28(4)** 445-452.

33. Mackert JR Jr & Wahl MJ (2004) Are there acceptable alternatives to amalgam? *Journal of the California Dental Association* **32(7)** 601-610.

34. Roulet JF & Degrange M (1996) Inlay restorations *Journal of the California Dental Association* **24(9)** 48-62.

35. Dalpino PH, Francischone CE, Ishikiriama A & Franco EB (2002) Fracture resistance of teeth directly and indirectly restored with composite resin and indirectly restored with ceramic materials *American Journal of Dentistry* **15(6)** 389-396.

36. Santos C, Mondelli R, Francischone C, Lauris J & Navarro M (2004) Clinical evaluation of ceramic inlays and onlays made with two systems: A one-year follow-up *Journal of Adhesive Dentistry* **6(4)** 333-338.

37. Lutz E, Krejci I & Oldenburg TR (1986) Elimination of polymerization stresses at the margins of posterior composite resin restorations: A new restorative technique *Quintessence International* **17(12)** 777-784.

38. Versluis A, Douglas WH, Cross M & Sakaguchi RL (1996) Does an incremental filling technique reduce polymerization shrinkage stresses? *Journal of Dental Research* **75(3)** 871-878.

39. Cvar JF & Ryge G (2006) Reprint of criteria for the clinical evaluation of dental restorative materials *Clinical Oral Investigations* **10(1)** 92.

40. Kaplan EL & Meier P (1958) Non-parametric estimation from incomplete observations *Journal of the American Statistical Association* **53(282)** 457-481.