Three-year comparison of fired ceramic inlays cemented with composite resin or glass ionomer cement

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Ceramic inlays offer a good alternative to posterior composites, which still show a high polymerization shrinkage. The thin cement layer will reduce the total amount of shrinkage and probably result in a better marginal adaptation and decreased marginal leakage. Fired feldspathic ceramic inlays cemented with either a glass ionomer cement or a dual-cured composite resin luting cement were compared intraindividually. During a 3-year period 118 inlays, 59 in each group, were examined. Eleven inlays were evaluated as non-acceptable during the period: two (3.4%) in the composite resin group and nine (15.3%) in the glass ionomer cement group. In the composite group one inlay fractured partially and one inlay was replaced because of postoperative sensitivity. In the glass ionomer group four inlays were totally lost, and partial fractures occurred in five inlays. In the fractured glass ionomer cemented inlays the cement was still in place in the cavities. Eight patients reported postoperative sensitivity. No secondary caries was detected around the inlays even though 46% of the patients were considered high caries risk patients. □ *Cementation; clinical evaluation; porcelain*

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The interest in alternative materials has grown rapidly, initiated by a demand for esthetic dentistry and by a concern about mercury toxicity. Despite the improved qualities of the posterior composites, they still show a relatively high polymerization shrinkage, leading to gap formation, which together with a substantial amount of occlusal wear limits their clinical use (1, 2). The idea of using ceramic inlays in posterior teeth was recognized a century ago. Disadvantages such as firing shrinkage, soluble cements, and brittleness under occlusal loading have been cited in the past. A historic view has recently been described (3). Fired etched ceramic inlays in combination with an adhesive cementing technique seem to provide a more wear-resistant posterior restoration. The porcelain also offers good biocompatibility and esthetics. The mechanical bond with a composite resin-luting cement will increase the strength of the porcelain inlay (4). The thin cement layer will reduce the total amount of shrinkage, probably resulting in better marginal adaptation and decreased marginal leakage (5–7). However, Feilzer et al. (8) disagree with this. Quite frequently, the cervical margin of posterior cavities ends below the enamel–cementum junction, which makes the bond to the tooth more difficult. Glass ionomer cements used as luting agents, introduced during the eighties, show good adaptation to enamel and dentin, low solubility in vivo, and release of fluoride over a long period of time, properties that make glass ionomer suitable as a luting agent, especially in deeper cavities (6). Both so-called adhesive luting techniques are preferable for their conservative, tooth tissue-saving cavity preparation. No long-term studies are available about the longevity of ceramic inlays or on the different cementing techniques used.

The purpose of this study was to evaluate longitudinally fired feldspathic ceramic inlays and to compare intraindividually two luting techniques, glass ionomer cement and dual-cured composite resin, used in combination with these inlays.

Materials and methods

Experimental design

One hundred and eighteen fired ceramic inlays, including eight onlays (Mirage, Chameleon Dental Products, Kansas City, Kan., USA), were placed in class-II cavities in 77 premolars and 41 molars. Forty-six inlays were placed in mandibular teeth and 72 in maxillary teeth. In no case did the inlays have occlusal contact with each other. Fifty patients, 17 men and 33 women (mean age: men, 30.5 years; women, 33.9 years; range, 19–70 years), regularly visiting the Umeå Dental School or a Public Dental Health Service Clinic (FTV, Vännäs), in whom ceramic inlays were indicated, were selected for the study. Each patient except for one received two or four inlays of the same size. In each patient, except one, the inlays were placed in the same type of tooth, premolar or molar. Fifteen inlays were placed because of primary caries and 103 because of secondary caries or replacement of amalgam fillings for other reasons. Box-shaped inlay cavities with slightly conical walls were prepared with preparation diamonds. All internal edges were rounded. Only small parts of the cavities, close to the pulp, were covered with isolated spots of calcium hydroxide cement (Dycal, DeTrey/Dentsply, Constance, Germany). Undercuts and deep parts of the cavities were covered with a glass ionomer cement base (Baseline, DeTrey/Dentsply). No enamel bevel was created. No enamel was found in the cervical wall of the proximal boxes for 21% of the patients. Most of the proximal cervical margins were located subgingivally. An impression was taken, using a custom-made acrylic tray and a polyvinyl siloxane material (Provil, Bayer Dental, Dormhagen, Germany). Temporary restorations were cemented with an eugenol-free cement. All test inlays/onlays were fabricated in accordance with the manufacturers' instructions within 2 weeks after tooth preparation. During the second appointment the inlays were tried out. The operation field was thoroughly isolated with cotton rolls and saliva suction equipment. After removal of the temporary restoration and cleaning of the cavities with a surface-active cavity cleanser (Tubulicid-blue, Dental Therapeutics Ltd, Ektorp, Sweden), anatomic form, marginal fit, and color of the inlays were checked initially before the cementing step, whereas occlusion was checked afterwards.

Luting agents

In each patient half of the inlays were cemented with a dual-cured composite resin luting agent (Mirage dual composite resin cement; batch 81 991) and the other half with a glass ionomer cement (Fuji I, GC Dental Industrial Corp, Tokyo, Japan).

Composite resin cementation. After the initial try-out the inlays were cleaned and re-etched for 2 min with 4% hydrofluoric acid and recoated with a silane solution necessary to restore the bond strength (7). During the conditioning of the inlay the enamel margins of the cavities were etched for 20–30 sec with 37% phosphoric acid gel. After thorough spraying with water for 30 sec and drying with compressed air, a thin transparent matrix band (Hawe Neos Dental, Gentilino, Switzerland) was placed around the preparation, and wooden wedges were placed. The cavities were covered with an enamel bonding agent (Mirage bonding agent), which was blown with a gentle stream of compressed air and not light-cured. The dual-cured composite resin cement was applied to the inlays and the inside of the cavities with a disposable brush and/or an application syringe. The inlays were quickly inserted with a minimum of pressure, and bulk excess composite was removed. The cement was light-activated for 60 sec each

Table 1. Criteria for direct clinical evaluation

Category	Score (acceptable)	Score (unacceptable)	Criteria
Anatomic form	0		The restoration is contiguous with tooth anatomy
	1		Slightly under- or over-contoured restoration; marginal ridges slightly undercontoured; contact slightly open (may be self-correcting); occlusal height reduced locally
		2	Restoration is undercontoured, dentin or base exposed; contact is faulty, not self-correcting; occlusal height reduced; occlusion affected
		3	Restoration is missing or traumatic occlusion; restoration causes pain in tooth or adjacent tissue
Marginal adaptation	0		Restoration is contiguous with existing anatomic form, explorer does not catch
	1		Explorer catches, no crevice is visible into which explorer will penetrate
	2		Crevice at margin, enamel exposed
		3	Obvious crevice at margin, dentin or base exposed
		4	Restoration mobile, fractured or missing
Color match	0		Very good color match, restoration almost invisible
	1		Good color match
	2		Slight mismatch in color, shade, or transluscency
		3	Obvious mismatch, outside the normal range
		4	Gross mismatch
Marginal discoloration	0		No discoloration evident
	1		Slight staining, can be polished away
	2		Obvious staining, cannot be polished away
		3	Gross staining
Surface roughness	0		Smooth surface
	1		Slightly rough or pitted
	2		Rough, cannot be refinished
		3	Surface deeply pitted, irregular grooves
Caries	0		No evidence of caries contiguous with the margin of the restoration
		1	Caries is evident contiguous with the margin of the restoration

from occlusal and buccal and lingual proximal aspects.

Glass ionomer cement cementation. After the initial try-out, matrix band placing, and wedging, the inlays were cleaned with ethanol. The cavities were than cleaned with 40% polyacrylic acid (Durelon liquid, ESPE, Seefeld, Germany) during 10–15 sec. After spraying with water, the cavities were dried gently, to prevent drying out of the dentin. The glass ionomer cement luting agent was mixed and applied to the inlays and/or cavities. The inlays were inserted, and after removal of gross excess, the luting agent was allowed to harden before the margins were covered with two thin layers of varnish and a layer of vaseline.

Occlusion and articulation were carefully checked after the cementing step. The inlays were then finished with finishing diamonds of different grits and polishing stones (Cerapearl system, Edenta AG, Switzerland). After 1 week final polishing of the inlays was done with a very fine diamond paste as the last step (Ultradent Products Inc, SLC, Utah, USA).

Evaluation

The inlays were evaluated by two investigators, trained and calibrated to make the assessments, directly after the final polishing (base line) and 6, 12, 24, and 36 months after cementation. The assessments of the inlays were made without knowledge of the cement used. Variables for evaluating the quality of the inlays (Table 1) are a slight modification

Table 2. Cumulative frequency of non-acceptable inlays and defective, but still acceptable, inlays in the two experiment groups after the 3-year evaluation period (%). Total number of inlays = 118, number of glass ionomer (GI) = 59; number of composite (C) = 59

	Non-acceptable			Defective		
	GI	C	Total	GI	C	Total
Base line	1.7	0	0.8	1.7	0	0.9
6 months	3.4	0	1.7	3.4	1.7	2.5
12 months	10.2	1.7	5.9	5.1	1.7	3.4
24 months	15.3	1.7	8.5	8.5	1.7	5.1
36 months	15.3	3.4	9.3	10.2	1.7	5.9

of the criteria of Cvar & Ryge (9, 10). Disagreement was resolved with forced consensus. Roentgenograms were taken for assessment of proximal marginal integrity and presence of recurrent caries. Postoperative sensitivity was determined by direct questioning. The gingival response was assessed by means of bleeding on probing and the absence or presence of plaque, both on the basis of a three-step scale (Table 4).

Potential caries activity

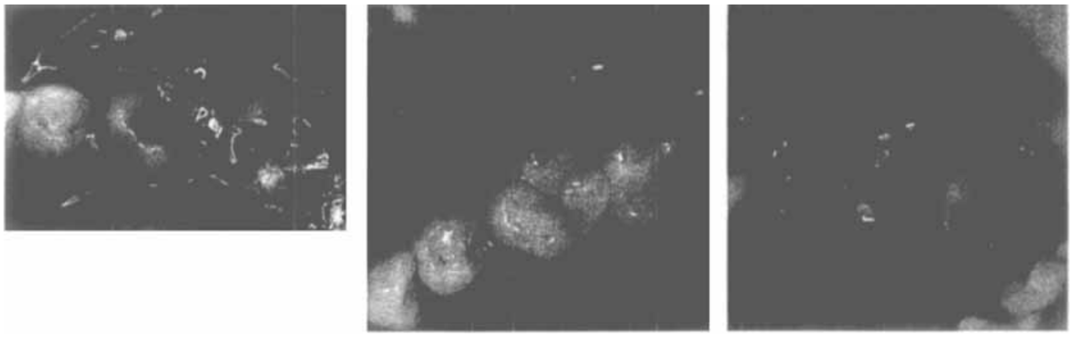
To evaluate the secondary caries risk around the inlays, a prediction of the caries risk of each patient, expressed as the potential caries activity, was made. The prediction was compared with the actual caries development in each patient. The caries risk prediction procedure has been used and published earlier (9, 11–12). The individual caries risk is estimated from the net effect of the patient's oral hygiene, intake of fermentable carbohydrates, salivary microbial counts, salivary flow rate, and buffer value. These factors were regarded as negative factors when certain values were exceeded. Oral hygiene was defined as a negative factor when a plaque score or a gingival bleeding was observed on more than 30% of the tooth surfaces. Intake of fermentable carbohydrates a mean of six times a day or more registered during 4 days was regarded as negative. The presence of more than 2.5×10^5 colony-forming units (CFU)/ml saliva of *Streptococcus mutans* or 10^5CFU/ml saliva of lactobacilli was regarded as a negative factor, as were a buffer value of 5.5 or lower and a flow rate of 0.7 ml/min or less. For each individual a maximum of six negative factors could thus be obtained.

Statistical analysis

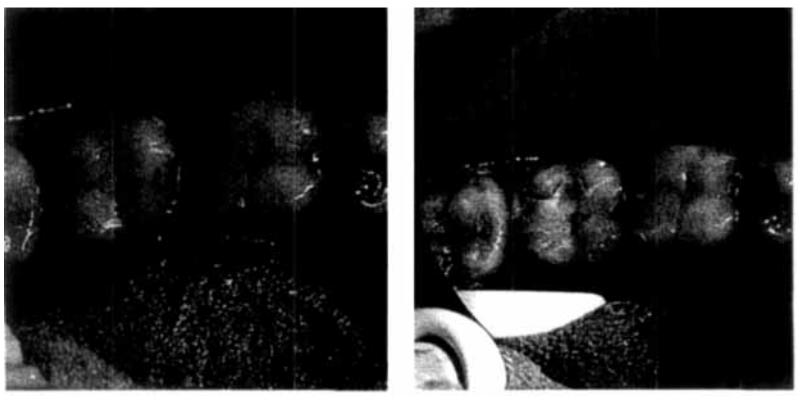
The evaluated characteristics of the test inlays are described by descriptive statistics by using frequency distributions of the scores. The durability of the two luting agents could be compared because each patient received the same number of inlays cemented with both of the luting agents. In this manner an intraindividual comparison of the inlays is possible, and each patient served as a statistical unit. In each patient the test inlays cemented with composite resin and glass ionomer cement were compared, by means of the received scores for all the clinically evaluated factors, and ranked. Durability of the adhesive techniques expressed by the sums of the individual ranks was tested by using Friedman's two-way analysis of variance test (13). The null hypothesis was rejected at the 5% level.

Results

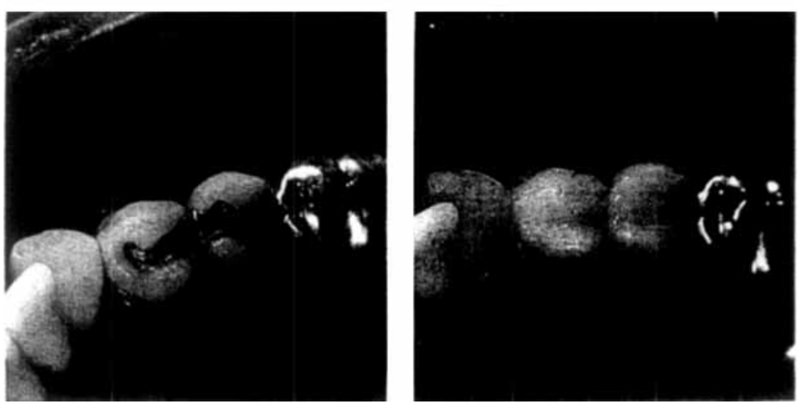
All patients were examined at all the recalls during the 3-year study period. The cumulative frequency of non-acceptable inlays and inlays with small but acceptable defects is shown in Table 2. Eleven inlays were evaluated as non-acceptable during the evaluation period, two in the composite group and nine in the glass ionomer group. In the composite group one inlay fractured partially (Figs. 1–3), and one inlay was replaced because of postoperative sensitivity. In the glass ionomer group four inlays were totally lost, and partial fractures occurred in five inlays (Figs. 4–7). In the cavities of the fractured glass ionomer-cemented inlays the cement still protected the dentin. Small defects in the form of chip fractures but still inside the acceptable score range, which could easily be repaired, occurred in eight of the inlays



Figs. 1–3. Ceramic inlays, in tooth 46 cemented with composite resin and in tooth 47 with glass ionomer cement, before preparation, at base line, and after 1 year, showing partial fracture of the inlay in tooth 46.



Figs. 4 and 5. Ceramic inlays, in tooth 36 cemented with composite resin and in tooth 37 with glass ionomer cement, at base line and after 2 years, showing a partial fracture of the inlay in tooth 37. Glass ionomer cement is still covering the cavity.



Figs. 6 and 7. Inlays in tooth 45 cemented with composite resin and in tooth 44 with glass ionomer cement, at base line and after 3 years, with good durability for both inlays.

Table 3. Frequency distribution of the scores for the investigated variables of the two inlay groups at the 3-year control visit. Failed inlays are included

	Glass ionomer (%)						Composite (%)					
	No.	0	1	2	3	4	No.	0	1	2	3	4
AF	59	67.8	17.0	1.7	13.5		59	76.3	22.0	0	1.7	
MA	59	6.7	73.0	5.1	1.7	13.5	59	38.9	56.1	3.3	0	1.7
CM	51	13.7	82.3	4.0	0	0	58	41.3	58.7	0	0	0
MD	51	94.3	4.0	1.7	0	0	58	89.6	10.4	0	0	0
SR	51	6.1	90.5	1.7	1.7		58	10.3	88.0	1.7	0	

AF = anatomic form; MA = marginal adaptation; CM = color match; MD = marginal discoloration; SR = surface roughness.

(seven in the glass ionomer group and one in the composite).

Eight patients reported postoperative sensitivity. Three patients reported temperature sensitivity during periods varying from 1 week to 2 months (three composite and one glass ionomer cement-luted inlay). Five patients showed sensitivity to loading (three in the composite group and two in the glass ionomer), which disappeared within 6 months for four of the patients. The fifth inlay, a composite-luted one, was replaced because of sensitivity to occlusal loading and temperature at the end of the 3-year period.

Frequencies of the scores for the evaluated factors at the 3-year visit are given in Table 3. Very good anatomic form was seen after 3 years in 67.8% of the glass ionomer-luted inlays and in 76.3% of the composite-luted ones. Excellent marginal adaptation was only found in 6.7% of the glass ionomer group and in 38.9% of the composite group.

All inlays in both cementing groups showed acceptable color match during the whole evaluation period, but the inlays in the composite group matched better than the glass ionomer-cemented inlays. Almost no marginal discoloration was observed in either of the experimental groups. After occlusal adjustment it was not possible to obtain a lasting surface polish comparable to the glazed porcelain. There was no difference in surface roughness between the two experimental groups. Plaque and gingivitis scores did not differ significantly during the various evaluations. The 3-year scores are shown in Table 4. No differences were seen between the glass ionomer- and the composite-luted inlays.

Table 4. Frequency of plaque and gingivitis on/around the experimental inlays at the 3-year control

	Glass ionomer			Composite resin		
	0	1	2	0	1	2
Plaque	15.7	68.8	15.6	17.2	63.9	18.9
Gingivitis	27.4	52.9	19.7	27.5	51.7	20.8

Plaque score: 0 = no plaque; 1 = plaque found by probing; 2 = visible plaque; gingivitis: 0 = no visible sign of gingivitis; 1 = redness; 2 = bleeding on probing.

The caries risk of the individual patients expressed as number of negative factors obtained is shown in Table 5. Forty-six per cent of the patients had three or more negative factors and are considered high caries risk patients (9). No secondary caries was detected around the inlays during the 3-year evaluation.

The intraindividual ranking of the inlays cemented with the two test luting agents showed a statistically significant difference between the glass ionomer cement-luted inlays and the composite-luted ones with regard to clinical durability ($p < 0.001$).

Discussion

Fired porcelain inlays are very brittle and are dependent on an adequate bonding to the tooth. Resistance to fracture and marginal breakdown of porcelain inlays and onlays are probably the most important factors influencing their durability. This requires adhesive properties of the luting agent to both the porcelain inlay and the hard tissues for retention and also a high resistance to chemical degradation.

Glass ionomer cement used as a luting agent has many advantages, such as adhesive properties to enamel and dentin and low solubility and fluoride release. On the other hand, the material is very technique-sensitive. Lower fracture strength values in vitro have been reported for porcelain inlays luted with glass ionomer cement than for composite resin-luted inlays (14, 15). Further, larger shear stresses were seen in the occlusal part of the ishtmus area in the glass ionomer-luted inlays, indicating that the composite resin could function better under loaded inlays. Dérand (14) showed lower shear stresses in the composite resin without adhesion to dentin compared with the glass ionomer cement luting. Dietsche et al. (15) showed in vitro that the adhesion of glass ionomer to dentin and enamel exceeded the bond to porcelain. The adhesion of glass ionomer to etched porcelain was inferior to the micromechanical and chemical bonding of composite resins to the porcelain. They suggested that after loading adhesive failure will occur between the ceramic and the glass ionomer cement. The high prevalence of inlay fractures in the glass ionomer group in this study, mostly occurring at the ceramic/cement interface, confirm the in vitro results. Fracture strength has also been related to the surface porosity of porcelain (16). Obliteration of the micropores and porosities, created by the hydrofluoric acid etch, by composite resin strengthens the brittle porcelain by a micromechanical interlocking between the resin and porcelain (16). Microcracks formed during the early setting stages of the glass ionomer can become of clinical importance (17). SEM observations of the porcelain inlays in this study showed medium cement layer thickness values varying from 83 μm to 142.5 μm (18). Davidson et al. (19) showed that the effect of the thickness of the cement layer on the stress depends on the nature of the cement. The thicker the glass ionomer layer, the faster the stress development. Composite resin showed an inverse relation. The early stress development and microcrack formation can have a detrimental effect on the bond strength of the aged cement.

Table 5. Potential caries activity of the experiment patients expressed as number negative factors found in each individual

No. of negative factors	No. of patients	%
0	4	8
1	8	16
2	15	30
3	8	16
4	11	22
5	4	8
6	0	0

In the composite resin group in this study the total failure after 3 years was 3.4%. One of two failures was a bulk fracture (1.7%) observed during the 3-year period. A higher fracture frequency (5.8%) was reported by Isenberg et al. (20) for Vita and Dicor inlays produced by the CAD/CAM technique after a 3-year follow-up. Jenssen (21) reported a 5.9% failure rate of resin-bonded Mirage inlays after 2 years. Christensen et al. (22) reported a 12% failure rate of fired porcelain inlays after a 2-year evaluation of different tooth-colored inlay systems made by general practitioners. Studer et al. (23) reported a 2.3% fracture rate after 18 ± 6 months' evaluation of Empress inlays made in general practice. Only one other study has evaluated glass ionomer cement as luting agent for porcelain inlays (24). Stenberg & Matsson (24) studied 25 Dicor inlays during 2 years and reported a 8% failure rate in 2-surface inlays of limited dimensions and exclusion of patients with parafunctional habits. It has been suggested that porcelain inlays are contraindicated in patients with bruxism. In this study more than 15% of the patients showed signs that active bruxism had taken place during the evaluation period. Seven

(63.6%) of the fractured inlays occurred in these patients.

Both luting techniques studied showed far better marginal adaptation results when evaluated by the modified USPHS criteria than the earlier low clinical success of the conventional more soluble cements combined with ceramic inlays (25). However, after 3 years only a 38.9% excellent adaptation was observed in the composite group compared with 6.7% in the glass ionomer group. Glass ionomer cement showed clinically a slightly higher dissolution rate, especially during the 1st year, which seems to slow down during the following years.

A very high rate of good color match was seen in both groups. The glass ionomer-luted inlays showed less excellent matching than the composite-luted ones, probably because of the higher opacity of the cement. Almost no change in color match was seen during the 3 years. Marginal discoloration was hardly seen during the evaluation period, which is an accordance with the findings in other 2- to 3-year studies (20, 21). Combined with the absence of secondary caries this indicates and confirms the advantages of the inlay technique, with reduced shrinkage resulting in less microleakage.

The surface ratings indicate slightly rough surfaces in both groups. The necessary adjustment to be made after seating of the inlay, which is one of the disadvantages of the ceramic inlay, produces a rough surface. Furthermore, after intensive polishing procedures the surface polish will never be as good as the glazed surface produced in the dental laboratory. Plaque-free surfaces were only found in 15%, which is in accordance with the findings of Sjögren et al. (26) on 12- to 24-month-old Cerec inlays. The degree of gingivitis found in the present study was, however, lower.

In the present study eight patients reported postoperative sensitivity around one of their inlays (6.8%), which lasted from 1 week to 6 months, except for in one patient. In this case the inlay was replaced after 3 years' sensitivity to occlusal loading and temperature. After replacement the symptoms disappeared. In other evaluations of ceramic inlays the frequencies of postoperative sensitivity vary quite a lot. Molin & Karlsson (27) reported a 3.9% non-permanent hypersensitivity in a cross-sectional study of Optec inlays with a medium age of 8.1 months. But they also reported that two inlays were replaced owing to severe hypersensitivity but did not not include these in the study. A higher frequency was found by Sjögren et al. (26) in a cross-sectional study of Cerec inlays, 12–24 months after cementation, reporting that 14% of the patients had symptoms. In one case endodontic treatment was necessary. Roulet & Herder (25) registered a very high initial postoperative sensitivity to percussion and temperature in 30% of the patients receiving Dicor inlays. On the other hand, Stenberg & Matsson (24) reported no symptoms and concluded that postoperative sensitivity in ceramic inlays cemented with glass ionomer and of limited dimension is an insignificant problem. In the present study, presumably because more extensive inlays were used—94% of the inlays were replacements of amalgam fillings—more symptoms were found.

The major reason for replacement in operative dentistry is secondary caries. Unfortunately, in most clinical evaluations of restorations little or no attention is given to the caries activity of the patients included. The multifactorial approach towards predicting caries activity used in this study has been scientifically tested in several clinical longitudinal studies (9, 11, 12). Its value has been proved for evaluation of current caries risk of individual patients and showed clearly, for example, the high secondary caries risk of composite fillings (9). After 3 years no secondary caries was found around the evaluated inlays in this study even though almost half of the patients showed high caries risk. All patients received individually adjusted prophylaxis, but still several of the patients developed caries in non-experimental teeth. Low caries prevalence is also reported in other studies of ceramic inlays (20, 21, 23, 24, 28, 29). However, in none of these studies was it indicated whether high caries risk patients were involved. Despite the relatively short evaluation period it can be concluded that the marginal sealing of the inlays with the cements used was sufficient to preclude the occurrence of secondary caries. Longer evaluation periods are now necessary to evaluate the aging of the sealing, especially of the more successful composite resin cement. The dual-cured composite resin cements, such as the one used in our study, were introduced to overcome a disadvantage of light-cured composites with their restricted depth of cure. However, the dual-cure composites still have limitations. They do not cure well by chemical means alone. When light is excluded, the setting reaction is very slow and incomplete. The effect of the light reaches only to a certain depth in the optimum intensity, and this cannot be compensated for by increased exposure times. Clinically, conversion of the luting agent will always decrease by transmission of the light through tooth and inlay. In this study a glass ionomer base was used to overcome this problem partly, and therefore no direct conclusions can be made about the clinical importance of the decreased conversion rate in parts of the cement layer. The use of chemically cured composites or perhaps the use of laser will overcome the restricted depth of cure problem. With the use of chemically cured composites a reduction in shrinkage stress can also be expected, resulting in better marginal adaptation (30).

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