Computer-Aided Direct Ceramic Restorations: A 10-Year Prospective Clinical Study of Cerec CAD/CAM Inlays and Onlays

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Purpose: The objective of this follow-up study was to examine the performance of Cerec inlays and onlays in terms of clinical quality over a functional period of 10 years. **Materials and Methods:** Of 200 Cerec inlays and onlays placed in a private practice between 1989 and early 1991, 187 restorations were observed over a period of 10 years. The restorations were fabricated chairside using the Cerec-1 computer-aided design/manufacturing (CAD/CAM) method and Vita MK I feldspathic ceramic. An adhesive technique and luting composite resin were used for seating the restorations. After 10 years, the clinical performance of the restorations was evaluated using modified USPHS criteria. The results were used to classify success and failure. **Results:** According to Kaplan-Meier analysis, the success rate of Cerec inlays and onlays dropped to 90.4% after 10 years. A total of 15 (8%) failures were found in 11 patients. Of these failures, 73% were caused by either ceramic fractures (53%) or tooth fractures (20%). The reasons for the remaining failures were caries (20%) and endodontic problems (7%). The three-surface Cerec reconstructions were found to have the most failures. **Conclusion:** The failure rate of 8% and the drop of the survival probability rate to 90.4% after 10 years of clinical service of Cerec-1 CAD/CAM restorations made of Vita MK I feldspathic ceramic appear to be acceptable in private practice. This is particularly true in light of the very high patient satisfaction. *Int J Prosthodont 2002;15:122–128.*

The fast development of digital computer technology in the early 1980s led to research into related applications in dentistry. The aim was to provide clinicians in private offices with the possibility to independently design and also machine dental ceramic restorations in an efficient and easy manner. Of the three most developed systems based on the computer-aided design/manufacturing (CAD/CAM) technology,[1–3] the Cerec system[4] was the most promising. A major company (Siemens, now Sirona Dental Systems) developed the system further so that it could be launched on the market in 1988.

In the Cerec system, an optical impression is taken with a small, intraoral three-dimensional camera and subsequently saved on a chip. The corresponding information is transmitted to a computer system and can then be further processed by the clinician interactively (CAD). These data are used for the grinding of an industrially prefabricated block of feldspathic ceramic with a diamond-coated milling disk incorporated in a three-axis milling unit (CAM). In 1987, field studies were conducted in selected dental offices,[5] and at the end of 1988, the Cerec-1 system was introduced to the market on a broad basis.

Because at that time long-term clinical studies were lacking not only for CAD/CAM ceramic restorations, but also for the adhesive seating of these ceramic restorations, it was decided to make a follow-up study on Cerec restorations placed in private practice and to check the treatment results at regular intervals. Two hundred Cerec inlays and onlays produced in a continuous sequence in a private practice were checked after 2 years[6] and 5 years[7] of service time. The objective of this study was to examine the clinical treatment results with Cerec inlays and onlays after a 10-year functional period.

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Table 1 Distribution of Cerec Inlays and Onlays

Type of restoration	Molars		Premolars		Maxillary canines	Total
	Maxillary	Mandibular	Maxillary	Mandibular		
One surface	7	13	1	2	0	23
Two surfaces	18	21	14	13	1	67
Three surfaces	20	20	38	7	0	85
≥ four surfaces	9	14	2	0	0	25
Total	54	68	55	22	1	200

Materials and Methods

Patients and Indications

Between May 1989 and March 1991, a total of 200 Cerec inlays and onlays were placed in 108 patients (62 female, 46 male). All of the patients had been recruited from a single private dental office. The mean age of the patients was 37 years (range 17 to 75 years). All patients presented with good dental care and a low risk for caries. They were also integrated into a regular dental hygiene recall scheme. The patients wished to have an esthetic restoration without the use of amalgam. The reason for choosing the Cerec method was the possibility to have an inlay or onlay produced and inserted chairside, without physical impression taking or having to wear a temporary restoration.

Of the 200 inlays and onlays placed, 85 (43%) were three-surface, 67 (33%) were two-surface, and 23 (11.5%) were one-surface inlays; 14 (7%) were multisurface inlays with buccal or oral extentions; eight (4%) were onlays with one cusp; and three (1.5%) were onlays with two cusps. The multisurface inlays and onlays were included in a group with 25 (13%) onlays with four or more surfaces. The inlays and onlays were placed in 54 (27%) maxillary molars and 68 (34%) mandibular molars, as well as in 55 (28%) maxillary premolars and 22 (11%) mandibular premolars. One inlay was used to restore a maxillary canine (Table 1).The mean functional life of the inlays and onlays was 10 years 3 months, ranging from 9 years 2 months to 11 years 5 months.

Treatment

According to the instructions in the Cerec manual, the cavities were prepared using an 80-μm diamond and finished with a 25-μm diamond (Intensiv Cerec-Prepset). All Cerec inlay and onlay reconstructions were conducted by the same operator. All cavities were treated strictly using a rubber dam (Ivory, Heraeus Kulzer); for the base, a glass-ionomer cement (77% Ketac-Bond, ESPE; 23% Vitre-Bond, 3M) was used. The areas near the pulp were treated beforehand with the localized application of a calcium hydroxide liner (Kerrlife, Kerr). All inlays and onlays were machined using the Cerec-1 hardware (Sirona) with a hydro drive and the first-generation software COS 1.

Feldspathic ceramic blocks (Vita Cerec MK I, Vita) were used exclusively. These ceramic reconstructions were etched with a 5% hydrofluoric acid (Cerec-Etch, Vita); 86% of the inlays and onlays were silanized before placement (Silicoup, Heraeus Kulzer). For the enamel etching, 35% phosphoric acid (Scotchgel, 3M) was used. The etching duration was reduced from initially 40 seconds for the first 17% of the inlays and onlays to 20 seconds to avoid posttreatment discomfort. A layer of bonding agent (Cerec-Bond, Heraeus Kulzer) was applied to the cavities, and the inlays and onlays were subsequently placed with luting composite resin (Cerec Duo-Cement, Heraeus Kulzer). To avoid overfilled margins, a transparent matrix (Universal Contouring Strip, Dentsply/DeTrey; Lucifix, Hawe Dental) was fixed interdentally with wooden wedges (Hawe Dental). For the curing of the luting agent, a polymerization light was used three to five times for 20 seconds each time (Elipar II, ESPE). The occlusion was contoured and finished with 40-μm and 15-μm diamond burs (Composhape Set, Intensiv). The approximal surfaces were treated with corresponding diamond-coated mechanical interdental files (Proxoshape Set, Intensiv). They were polished with flexible disks in four steps (Sof-Lex, 3M) and interdental polishing strips (3M). Finally, topical fluoride (Elmex-Fluid, Gaba) was applied to the treated teeth.

Clinical Evaluation

Immediately after placement, the initial clinical quality of the inlays and onlays was assessed using the modified United States Public Health Service (USPHS) criteria[8] (Table 2). Mismatch in color, shape, or contour was recorded in the patient file and photographically documented (Table 3).

After 10 years, the inlays and onlays were visually checked with a mirror and classified again according to the modified USPHS criteria (Table 3). An explorer

Table 2 Modified USPHS Criteria Used for Classification of Inlays

Rating	Criteria
Margin quality (using mirror and explorer)	
A	No catches at cavity margin, but if present, overhangs and underfilled margins are invisible
B	Probe catches at cavity margin; visible overhangs and underfilled margins; no exposed dentin or base material
C	Probe catches at cavity margin; visible overhangs and underfilled margins; exposed dentin or base material; immobile and uncracked filling
D	Fractured or missing filling
Contour (using mirror, explorer, and waxed dental floss)	
A	Surface morphology correct; perhaps overcontoured; tight proximal contacts
B	Surface morphology incorrect; perhaps undercontoured; weak proximal contacts
C	Defective restoration; exposed dentin or base material; open proximal contacts
Surface texture (using mirror and explorer)	
A	Visually smooth surface; no tactile roughness
B	Visible and tactile surface roughness; no pitting or craters; unpolished fissures
C	Pitted surface or surface with craters; overall insufficient polish
Color match (using mirror)	
A	No apparent color change, retaining shiny surface
B	Minimal loss of translucency, but within range of normal tooth color (≤ one Vita shade off)
C	Severe surface dulling, not within range of normal tooth color (> one Vita shade off)

Table 3 USPHS Rating of Restorations at Baseline (B) and After 10 Years

	Molars (n = 109)		Premolars (n = 77)		Three surfaces (n = 84)		One and two surfaces (n = 88)		≥ four surfaces (n = 15)	
Rating	B	10 y	B	10 y	B	10 y	B	10 y	B	10 y
Margin quality										
A	90	28	66	20	72	19	76	19	11	2
B	19	75	11	54	12	58	12	67	4	13
C	0	1	0	0	0	1	0	0	0	0
D	0	5	0	3	0	6	0	2	0	0
Contour										
A	68	51	45	38	51	39	54	45	8	6
B	41	54	32	38	33	43	34	47	7	8
C	0	4	0	1	0	2	0	2	0	1
Surface texture										
A	80	40	54	30	61	32	65	34	11	5
B	29	68	23	47	23	51	23	54	4	10
C	0	1	0	0	0	1	0	0	0	0
Color match										
A	82	71	59	50	65	55	68	56	11	9
B	27	38	18	27	19	29	20	32	4	6
C	0	0	0	0	0	0	0	0	0	0

(S23, Deppeler) was used for tactile examination of the margins and the surface quality. Waxed dental floss (ACT, Johnson & Johnson) was used for checking the approximal contacts. The patients were also given a questionnaire asking for their subjective satisfaction and possible posttreatment discomfort after the placement of the restorations. In addition, sensibility was tested with a CO_2 test, and bitewing radiographs were taken of the posterior areas. Inlays and onlays that proved to be difficult to classify according to the deviation of color or contour were additionally documented photographically (Fig 1).

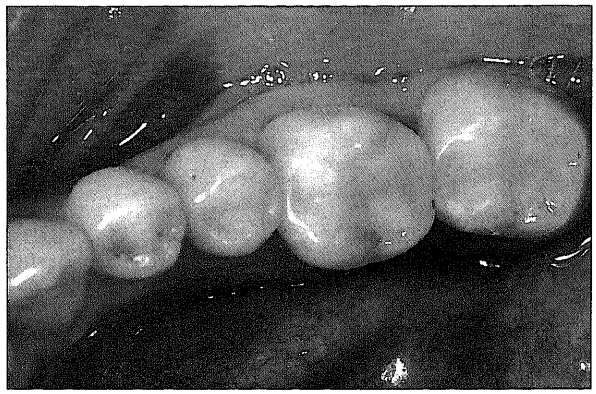
Inlays and onlays that did not show any clinical changes and did not require any adjustment were given an A rating. In the case of minor defects—moderate overhangs, underfilled margins, or small changes in texture or color, which did not impair the clinical result—inlays and onlays were rated as B. The C and D ratings were assigned to those inlays and onlays that required repairs or even a replacement restoration because of fractures or chipping. Furthermore, inlays and onlays that caused endodontic problems, persisting pain, or secondary caries were also rated as clinically unacceptable and as failing restorations at the time of diagnosis.

The clinical follow-up examinations were conducted by the authors. To agree on a common basis for the ratings at the reevaluation, the first 10 inlays and onlays were checked by both clinicians in parallel. In unclear cases, the photographic and radiologic documentation was used for decision making. If there was a disagreement among clinical,

Fig 1a *(right)* Three Cerec restorations at time of insertion (baseline).

Fig 1b *(below)* Three restorations at the time of clinical evaluation after 5 years.

Fig 1c *(below right)* After 10 years in function, the three restorations still show a good clinical result with regard to functional and esthetic aspects.



radiologic, and photographic assessment, the worst rating was chosen. Those inlays and onlays that had obtained an A or B rating in all test categories and had no caries, persisting pain, or vitality problems were considered successful.

Statistical Analysis

Based on the defined success criteria, the failure rate was calculated according to the Kaplan-Meier analysis[9] with Starter 6.0 software. Impacts on the failure rate were calculated using the Cox proportional hazards model.[10]

Results

Of the 200 Cerec inlays and onlays originally placed in 108 patients, 89 (82%) patients with 187 (94%) inlays and onlays were available for a follow-up examination after 10 years. According to the questionnaire, all patients were satisfied or very satisfied with their Cerec restorations. Posttreatment discomfort, mainly pain caused by occusal contact, occurred in 17 cases after placing the reconstructions. Among 12 patients, these symptoms disappeared within a few days to 3 weeks. However, in five patients these complaints persisted for several weeks and lasted up to 7 months, and then gradually diminished.

Of the 187 inlays and onlays in the follow-up examination, a total of 15 inlays and onlays in 11 patients were allocated a C or D rating, which qualified them as failures (Table 3). The failures occurred after a functional period of between 6 years 9 months and 9 years 9 months; two teeth had to be treated endodontically after 1.5 and 2 years, respectively, with the inlays remaining in situ (Table 4). One patient presented three failures. Two patients suffered two failures each, and in eight patients only one inlay or onlay had to be given an insufficient rating.

Based on the Kaplan-Meier analysis for all reconstructions, the survival probability dropped to 90.4% (95% confidental interval 0.8462 to 0.9408) after 10 years (Fig 2). In terms of type of reconstruction, the three-surface inlays proved to have significantly lower survival times (hazard ratio 1:3.96; Fig 3). With regard to the individual teeth, premolars present a slightly lower risk than molars, with the mandible yielding better results than the maxilla. Differentiated by gender, a nonsignificantly higher risk for failures was seen in male patients. The most frequent reason for the 15 failures was ceramic fractures of eight (53%) inlays and onlays and three (20%) fractured cusps of reconstructed teeth. Other

Table 4 Details About the 15 Restorations Rated C or D According to USPHS Criteria

Restoration	Time in function	Reason for failure	Consequences of failure
1	6 y 9 mo	Ceramic fracture	New Cerec
2	7 y 5 mo	Ceramic fracture	Repair with composite
3	7 y 6 mo	Ceramic fracture	Repair with composite
4	7 y 7 mo	Tooth fracture	Crown
5	7 y 8 mo	Ceramic fracture	Repair with composite
6	8 y 5 mo	Tooth fracture	Crown
7	8 y 8 mo	Tooth fracture; endodontics 1 y 5 mo	Crown
8	8 y 10 mo	Ceramic fracture	New Cerec
9	8 y 10 mo	New caries	Composite filling
10	8 y 11 mo	Ceramic fracture	New Cerec
11	9 y	Ceramic fracture	New Cerec
12	9 y 2 mo	Ceramic fracture	New Cerec
13	9 y 8 mo	Marginal caries	New Cerec
14	9 y 9 mo	New caries	Composite filling
15	10 y 7 mo	Endodontics 2 y 1 mo	Small Cerec within restoration (still in use)

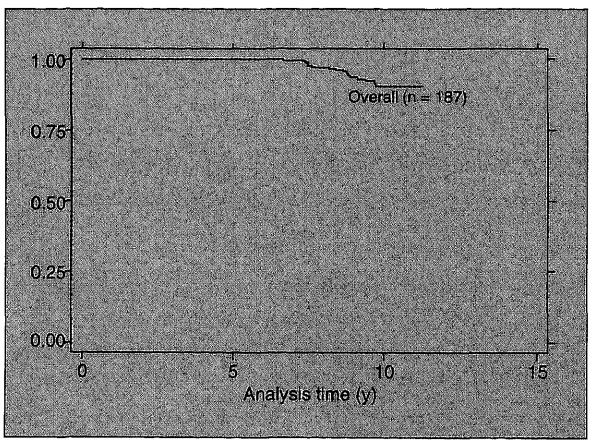


Fig 2 Kaplan-Meier survival estimate for all restorations (n = 187; 15 failures).

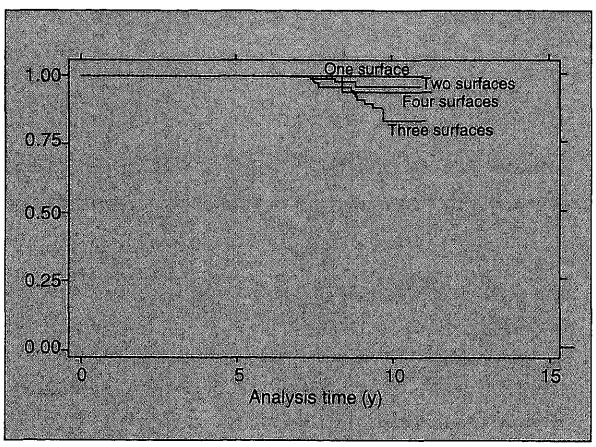


Fig 3 Kaplan-Meier survival estimate by surface.

reasons for failures were new caries, secondary caries, and endodontic problems (Table 4). Two of the three patients with multiple failures presented with distinct bruxism. The failed restorations were repaired with composite or replaced by new Cerec restorations or porcelain-fused-to-metal crowns (Table 4).

Of the 172 inlays and onlays with a clinically satisfactory rating, those with a B rating after 10 years according to margins increased from 12% to 74%. In the assessment of the contours, the share of the B-grade inlays and onlays increased from 39% to 51%, with regard to the surface structure from 27% to 62%, and with regard to the color characteristics from an initial 24% to 35% after 10 years (Table 3).

Discussion

After a period of 10 years, a follow-up examination was conducted on 82% of the patients and 94% of the initially placed inlays and onlays. The low dropout rate is due on the one hand to the fact that patients with private health care schemes do not tend to change their dentists often, and on the other hand to the fact that all patients had been treated in one dental office by the same clinician. To overcome the weakness of the study, the fact that the treating clinician also did a part of the examinations, the authors tried to calibrate themselves. Because of the clear definition of a successful restoration, there were only a few uncertain classifications with respect to A and B ratings of color match and surface texture.

All patients declared themselves to be satisfied or very satisfied with their Cerec restorations, even though some of them had suffered posttreatment discomfort after placement[11] or failing restorations. The reason for this might be the high motivation of these patients toward a new high-tech method.

The Kaplan-Meier survival rate of 187 inlays and onlays over 10 years was 90.4%. This meant that 11 of 89 patients (12%) had suffered at least one failure. In six of the 15 inlays and onlays rated as failures, a simple repair with composite material or ceramic was possible, with the original Cerec restoration remaining in situ. Consequently, nine (5%) of the 187 restorations had to be replaced during the 10-year observation period. Of these, six teeth were reconstructed with new Cerec restorations, preserving the hard tissue. Only three (1.6%) of the teeth examined during the follow-up period had to be retreated using an invasive method, in these cases with a crown. These favorable results are in line with the results found by other authors[12] who had reported a success probability of 90%.

It is not possible to compare these results to other indirect ceramic reconstruction methods, since there are no studies available for such a period of time. Comparison studies over 5 years,[13] however, yielded similar results for various ceramic reconstruction methods. In a comparable study on Empress inlays (Ivoclar) over 6 years,[14] a survival rate of 95% was found, a result similar to those established for laboratory-made ceramic inlays.

Some of the various publications on the survival rate of amalgam fillings and corresponding long-term results[15,16] present distinctly less favorable results compared to Cerec inlays and onlays and a lower survival rate (61% and 67%) after 5 years. However, these results might be influenced by the specific alloy used.[17] In addition, there are only a few, short-term clinical examinations for composite fillings or composite inlays,[18,19] which show higher failure rates of 12% to 24% after 6 years and of 8% as early as after 3 years.

Of the 15 failures observed in the present study, 53% were caused by fractures of the ceramic block. These results are similar to other studies on Cerec inlays.[12] Also, in other indirect ceramic restoration systems, ceramic fractures clearly outweigh the other causes for failure.[13,14] In two cases, cusp fractures were seen, and in one case a cusp suffered a fracture after an endodontic treatment of the corresponding tooth. Reiss and Walther[12] reported significantly lower survival rates of Cerec inlays because of tooth fractures in nonvital teeth compared to vital teeth.

In one case only, secondary caries was found at a restoration margin. There was a general, self-limiting loss of bonding composite out of the luting interface during the first year after placement.[20] This explains the slightly underfilled margins that could be found with an explorer. The occurrence of underfilled margins increased from 12% after placement to 74% after 10 years, but did not seem to favor the occurrence of secondary caries. The consistent use of the adhesive technique for the placement of ceramic inlays and onlays with luting composite[21] also seemed to yield clinically sufficient results with the Cerec-1 method, where there are relatively large luting interfaces of up to 150 μm.[20,22]

The relative changes in color, surface, or shape of the inlays and onlays that occurred over the period of 10 years may be caused by a change in the color and translucence of the natural dentition, as well as by occlusal contacts, mechanical stress, and chemical degradation. No clinical consequence could be deduced from this fact, since there is no correlation between these changes and the failures, and since they were not actively perceived by the patients and were not recognizable from beyond a talking distance.

Statistically, the failure probability was highest in the three-surface Cerec inlays. The analyzed data did not provide any conclusive evidence as to whether this had technical causes or was due to the specific anatomic situation. In most cases, however, the fracture occurred at what was presumably the thinnest region of the inlay (isthmus fracture) or at the marginal ridge. This could be a hint that in such reconstructions, the minimum thickness of the ceramic should be observed. The fact that two to three patients with multiple failures were diagnosed with bruxism may be a hint that this particular group of patients should be considered a risk group with regard to Cerec restorations.

Based on these 10-year results of ceramic inlays and onlays with the Cerec-1 method and Vita MK I feldspathic ceramic, the continuation of this technique with the Cerec-2 and Cerec-3 technology, and therefore an extension to partial crown indications and possibly also to all-ceramic crowns, may open up a promising clinical potential. The fact that it is possible now to have control of the occlusal thickness before grinding the inlays and improved block-ceramic materials (Vita MK II, Vita; and ProCAD, Ivoclar/Vivadent) may help to prevent fractures of the ceramic restorations.

Conclusions

1. The failure rate of 8% and the drop of the survival probability rate to 90.4% after 10 years of clinical service of Cerec-1 CAD/CAM restorations

made of Vita MK I feldspathic ceramic appear to be acceptable in private practice.
2. To prevent ceramic or tooth fractures, care should be taken to observe minimal ceramic thickness, especially in isthmus areas and marginal ridges.
3. Ceramic restorations may not be indicated in patients with heavy bruxing habits.
4. Patient satisfaction with and acceptance of the CAD/CAM restorations produced chairside was very high.

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Literature Abstract

Acid conditioning combined with single-component and two-component dentin bonding agents.

The shear bond strength of human dentin surfaces treated with 24% EDTA or 32% phosphoric acid and one of two bonding agents (All-Bond 2, Bisco; Prime & Bond NT, Dentsply) was evaluated. Paired dentin surfaces were obtained from 21 extracted human third molars. The etching times were 15 seconds and 3 minutes for phosphoric acid and EDTA, respectively. EDTA–All-Bond 2 treatment provided 61% to 123% higher shear bond strength when compared to other combinations. The result was statistically significant. The authors attributed the beneficial effect of EDTA to its ability to selectively remove mineral without disturbing the collagenous matrix. This was said to be in contrast to the effect of phosphoric acid, which dissolves the mineral phase and causes the collagenous matrix to recede. The absence of EDTA's beneficial effect when used in combination with Prime & Bond NT was explained by the relative insensitivity of nanofilled primers such as Prime & Bond NT to the volume of dentin collagen exposed by etching.

Blomlöf J, Cederlund A, Jonsson B, Ohlson N. *Quintessence Int* 2001;32:711–715. **References:** 24.
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