# Long-Term Clinical Results of Chairside Cerec CAD/CAM Inlays and Onlays: A Case Series

Tobias Otto, Dr Med Dent[a]/David Schneider, Dr Med, Med Dent[b]

**Purpose:** The objective of this follow-up study was to examine the performance of Cerec inlays and onlays, all of which were placed by the same clinician, in terms of clinical quality over a functional period of 15 years. **Materials and Methods:** Of 200 Cerec inlays and onlays placed consecutively in a private practice by one of the authors (TO) between 1989 and early 1991, 187 were closely monitored over a period of 15 years. All ceramic inlays and onlays had been placed chairside using the Cerec 1 method and had been luted with a bonding composite. Up to 17 years after their placement, a follow-up assessment was conducted, and the restorations were classified using modified United States Public Health Service criteria. **Results:** According to Kaplan-Meier analysis, the success rate of Cerec inlays and onlays was 88.7% after 17 years. A total of 21 failures (11%) were found in 17 patients. Of these failures, 76% were attributed to ceramic fractures (62%) or tooth fractures (14%). The reasons for the remaining failures were caries (19%) and endodontic problems (5%). Restorations of premolars presented a lower failure risk than those of molars. **Conclusion:** The survival rate probability of 88.7% after up to 17 years of clinical service for Cerec computer-aided design/computer-assisted machining restorations made of Vita Mk I feldspathic ceramic is regarded as a very respectable clinical outcome. *Int J Prosthodont 2008;21:53–59.*

The rapid 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 ability to independently design and machine dental ceramic restorations in an efficient and easy manner. As a result of this, the Cerec System[1] (Sirona Dental Systems) was introduced in 1985 by Drs Mörmann and Brandestini at the University of Zurich (Switzerland). In the Cerec System, an optical impression of a tooth preparation is taken with a small optoelectronic videocamera and subsequently saved. The digital 3-dimensional (3D) information is transmitted to a computer and the dentist interactively designs the restoration on the screen (computer-aided design [CAD]). These data are used for the grinding of an industrially prefabricated feldspathic ceramic block with a diamond-coated disk incorporated into a 3-axis milling unit (computer-aided machining [CAM]).[2] In 1986, a dental products company (Siemens Dental, now Sirona Dental Systems) started developing the system further. In 1987, field studies were conducted in selected dental offices[3] and at the end of 1988, the Cerec 1 system was introduced to the market on a broad basis. Because long-term clinical studies were lacking at that time, not only for CAD/CAM ceramic restorations but also for the adhesive seating of these ceramic restorations, we decided to conduct a follow-up study on Cerec reconstructions placed in our private practice and to check the treatment results at regular intervals. Therefore, 200 Cerec inlays and onlays, produced in a continuous sequence in our practice, were checked after 2 years,[4] 5 years,[5] and 10 years.[6] The objective of the present study was to examine the results of clinical treatment with Cerec inlays and onlays after a 15-year functional period.

[a]*Private Practice, Aarau, Switzerland.*
[b]*Postgraduate Student, Clinic for Fixed and Removable Prosthodontics and Dental Materials, School of Dentistry, University of Zurich, Switzerland.*

***Correspondence to:*** *Dr Tobias Otto, Bahnhofstrasse 10, CH-5000 Aarau, Switzerland. Fax: +41-62-824-6726. E-mail: praxis.otto@bluewin.ch*

**Table 1** Distribution of Inlays and Onlays Placed

| No. of | Molars | | Premolars | | Canines | |
|---|---|---|---|---|---|---|
| surfaces | Max | Mand | Max | Mand | Max | Total |
| 1-surface | 7 | 13 | 1 | 2 | 0 | 23 |
| 2-surface | 18 | 21 | 14 | 13 | 1 | 67 |
| 3-surface | 20 | 20 | 38 | 7 | 0 | 85 |
| 4-surface | 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 women, 46 men) consecutively. The mean age of the patients was 37 years (range, 17 to 75 years). Because all patients had been trained in oral hygiene measures, the Cerec restoration group presented with good dental care and a low risk of caries and were integrated into a regular dental hygiene recall scheme. The patients desired an esthetic restoration without amalgam. The Cerec method was chosen because it was possible for patients to have a ceramic inlay or onlay produced and inserted in a single appointment; no physical impression-taking or provisional restorations were needed.

Of the total of 200 inlays and onlays that were placed, 85 (43%) were 3-surface inlays, 67 (34%) were 2-surface inlays, 23 (12%) were 1-surface inlays, 14 (7%) were multisurface inlays with buccal or oral extensions, 8 (4%) were onlays with 1 cusp, and 3 (1.5%) were onlays with 2 cusps. The multisurface inlays and all onlays were pooled and classified as a 4-surface group (n = 25, 13%). 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 reconstruct a maxillary canine (Table 1). The mean functional life of the inlays and onlays was 15 years and 8 months, ranging from 14 years 6 months up to 16 years 11 months.

### Restorative Treatment

According to the manufacturer's instructions, the cavities were prepared using an 80-µm diamond and were finished with a 25-µm diamond (Intensiv). All inlays and onlays were carried out by the same operator (TO). All cavities were treated strictly using rubber dam (Ivory, Heraeus-Kulzer); for the base, a glass-ionomer cement (77% Ketac-Bond, 3M/ESPE; 23% Vitre-Bond, 3M) was used. Any areas near pulp were treated before restoration with localized application of a calcium hydroxide liner (Life, KerrHawe).

All inlays and onlays were machined using the Cerec 1 hardware (Siemens, now Sirona) with a hydrodrive and the computer software COS 1.0. Feldspathic ceramic blocks (Vita Cerec Mk I, Vita Zahnfabrik) were used exclusively. These ceramic restorations were etched with 4.9% hydrofluoric acid (Cerec-Etch, Vita). Because silanization of the etched ceramic was added to the manufacturer's protocol, 86% of the inlays and onlays were silanized before placement (Silicoup, Heraeus-Kulzer). For the enamel etching, 35% phosphoric acid (Scotchgel, 3M) was used. Enamel etching was reduced from 40 seconds for the first 17% of the inlays and onlays to 20 seconds, to prevent 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 (Cerec Duo-Cement, Heraeus-Kulzer). To avoid overfilled margins, transparent matrices (Universal Contouring Strip, Dentsply-DeTrey; Lucifix, KerrHawe) were fixed interdentally with wooden wedges (KerrHawe). To cure the luting composite, a polymerization light, which was tested routinely with a light meter, was used 3 to 5 times for 20 seconds each time (Epilar II, 3M/ESPE).

The occlusion was designed and finished with 40-µm and 15-µm diamond burs (Composhape, Intensiv). The proximal surfaces were finished with corresponding diamond-coated mechanical interdental files (Proxoshape, Intensiv) and were polished using flexible disks in 4 steps (Sof-Lex, 3M) as well as interdental polishing strips (3M). Finally, a topical fluoride (Elmex-Fluid, Gaba) was applied to the treated tooth surface.

### Clinical Evaluation

The baseline examination of the inlays and onlays had been carried out by one of the authors (TO). After clinical service times of up to 17 years, 187 of the 200 inlays and onlays were reevaluated by a blinded examiner (DS). The restoration margins were examined visually and manually with a mirror and a probe (S23, Deppeler), and proximal contacts were checked with waxed dental floss (ACT, Johnson & Johnson) and classified according to the modified United States Public Health Service (USPHS) criteria[7] (Table 2). In addition, tooth vitality was tested with a carbon dioxide test, and 2 bitewing radiographs were obtained.

Inlays and onlays that were difficult to classify were also documented with photographs (Fig 1). Inlays and onlays that did not show any clinical changes and did not require any adjustments were rated Alpha.

**Table 2** Modified USPHS Criteria Used to Rate Inlays and Onlays

| Criterion | Description |
|---|---|
| Margin quality (using mirror and explorer) | |
| Alpha | No catches at cavity margin, but if present, overhangs and underfilled margins are invisible |
| Bravo | Probe catches at cavity margin, visible overhangs and underfilled margins, but no exposed dentin or base material |
| Charlie | Probe catches at cavity margin, visible overhangs and underfilled margins, exposed dentin or base material, immobile and uncracked filling |
| Delta | Fractured or missing filling |
| Contour (using mirror, explorer and waxed dental floss) | |
| Alpha | Surface morphology correct, perhaps overcontoured, tight proximal contacts |
| Bravo | Surface morphology correct, perhaps undercontoured, weak proximal contacts |
| Charlie | Defective restoration, exposed dentin or base material, open proximal contacts |
| Surface texture (using mirror and explorer) | |
| Alpha | Visually smooth surface, no tactile roughness |
| Bravo | Visible and tactile surface roughness, no pitting or craters, unpolished fissures |
| Charlie | Pitted surface or surface with craters, overall insufficient polish |
| Color matching (using mirror) | |
| Alpha | No apparent color change, retaining shiny surface |
| Bravo | Minimal loss of translucency, but within the range of normal tooth color (= 1 Vita shade off) |
| Charlie | Severe surface dulling, not within the range of normal tooth color (> 1 Vita shade off) |

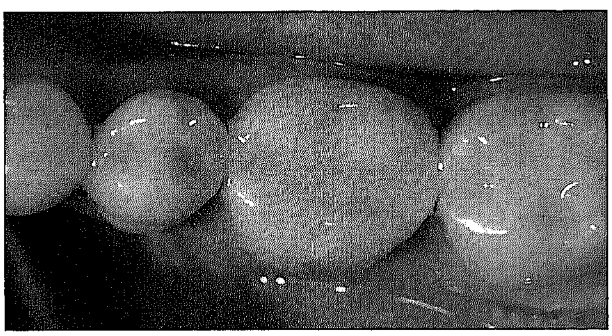

**Fig 1a** Two Cerec restorations at time of insertion (baseline).

**Fig 1b** After 16 years in function, these 2 Cerec restorations still show a good clinical result with regard to functional and esthetic aspects.

Restorations with minor defects, such as moderate overhangs, underfilled margins, or small changes in texture or color, that did not affect the clinical result were rated Bravo. The Charlie and Delta criteria were assigned to those inlays and onlays that required repairs or even replacement because of fractures, chipping, or major defects. Furthermore, inlays and onlays that caused sensitivity problems, persistent pain, or secondary caries were also rated Delta. To agree on a common basis for the baseline and follow-up ratings at time of the reevaluation, the first 10 inlays and onlays were checked by the blinded examiner (DS) and the author (TO) in parallel. When a decision could not be made easily, photographic and radiologic documentation was used for decision-making. If there was disagreement following clinical, radiologic, and photographic assessment, the worse rating was chosen. Inlays and onlays that obtained Alpha or Bravo ratings for all criteria were considered successful.

### *Statistical Analysis*

Based on the defined success criteria, the failure rate was calculated according to the Kaplan-Meier analysis[8] with Stata 8.0 software (Stata Corporation). The hazard ratios for different predictors were calculated using the Cox proportional hazards model.[9]

## 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 follow-up examination after a maximum of 16 years and 11 months. Of the 187 inlays and onlays in the follow-up examination, a total of 21 (11%) inlays and onlays in 17 patients were allocated a Charlie or Delta rating, which qualified them as failures (Table 3). The failures occurred after a functional period of 6 years, 9 months, to 13 years, 10

**Table 3** USPHS Ratings of Restorations at Baseline (B) and After 15 Years

| USPHS criterion | Molars (n = 109) B | Molars (n = 109) 15 y | Premolars (n = 77) B | Premolars (n = 77) 15 y | 3-surface (n = 84) B | 3-surface (n = 84) 15 y | 2-surface (n = 66) B | 2-surface (n = 66) 15 y | 1-surface (n = 22) B | 1-surface (n = 22) 15 y | 4-surface (n = 15) B | 4-surface (n = 15) 15 y |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Margin quality | | | | | | | | | | | | |
| Alpha | 90 | 21 | 66 | 16 | 72 | 15 | 57 | 9 | 19 | 8 | 11 | 2 |
| Bravo | 19 | 80 | 11 | 57 | 12 | 60 | 9 | 55 | 3 | 12 | 4 | 13 |
| Charlie | 0 | 2 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| Delta | 0 | 6 | 0 | 4 | 0 | 8 | 0 | 1 | 0 | 2 | 0 | 0 |
| Contour | | | | | | | | | | | | |
| Alpha | 68 | 45 | 45 | 31 | 51 | 30 | 38 | 30 | 16 | 13 | 8 | 6 |
| Bravo | 41 | 57 | 32 | 45 | 33 | 51 | 28 | 33 | 6 | 9 | 7 | 8 |
| Charlie | 0 | 7 | 0 | 1 | 0 | 3 | 0 | 3 | 0 | 0 | 0 | 1 |
| Surface texture | | | | | | | | | | | | |
| Alpha | 80 | 31 | 54 | 21 | 61 | 24 | 50 | 20 | 15 | 10 | 11 | 4 |
| Bravo | 29 | 77 | 23 | 56 | 23 | 59 | 16 | 46 | 7 | 12 | 4 | 11 |
| Charlie | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Color matching | | | | | | | | | | | | |
| Alpha | 82 | 66 | 59 | 45 | 65 | 50 | 51 | 39 | 17 | 15 | 11 | 8 |
| Bravo | 27 | 43 | 18 | 32 | 19 | 34 | 15 | 27 | 5 | 7 | 4 | 7 |
| Charlie | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 4** Details of the 21 Failed Restorations

| Restoration | Time in function | Reason for failure (T/B) | Consequences of failure |
|---|---|---|---|
| #1 | 6 y 9 m | Ceramic fracture (T) | New Cerec |
| #2 | 7 y 5 m | Ceramic fracture (T) | Repair with composite |
| #3 | 7 y 6 m | Ceramic fracture (T) | Repair with composite |
| #4 | 7 y 7 m | Tooth fracture (B) | Crown |
| #5 | 7 y 8 m | Ceramic fracture (T) | Repair with composite |
| #6 | 8 y 3 m | Ceramic fracture (T) | Repair with composite |
| #7 | 8 y 5 m | Tooth fracture (B) | Crown |
| #8 | 8 y 8 m | Tooth fracture (B)<br>Endodontics 1 y 5 m (B) | Crown |
| #9 | 8 y 10 m | Ceramic fracture (T) | New Cerec |
| #10 | 8 y 10 m | New caries (B) | Composite filling |
| #11 | 8 y 11 m | Ceramic fracture (T) | New Cerec |
| #12 | 8 y 11 m | Ceramic fracture (T) | Repair with composite |
| #13 | 9 y | Ceramic fracture (T) | New Cerec |
| #14 | 9 y 2 m | Ceramic fracture (T) | New Cerec |
| #15 | 9 y 8 m | Marginal caries (T) | New Cerec |
| #16 | 9 y 9 m | New caries (B) | Composite filling |
| #17 | 10 y 4 m | Ceramic fracture (T) | Repair with composite |
| #18 | 10 y 7 m | Endodontics 2 y 1 m (B) | Small Cerec within restoration (still in use) |
| #19 | 13 y 6 m | Marginal caries (B) | New Cerec |
| #20 | 13 y 8 m | Ceramic fracture (T) | Repair with composite |
| #21 | 13 y 10 m | Ceramic fracture (T) | Repair with composite |

T = technical; B = biologic.

months, whereas 2 teeth had to be treated endodontically after 1.5 and 2 years, respectively, with the inlays remaining in situ (Table 4). One patient presented 3 failures. Two patients suffered 2 failures each, and in 14 patients, only 1 inlay or onlay was given an insufficient rating.

Based on the Kaplan-Meier analysis for all reconstructions, the survival probability dropped to 88.7% (95% confidence interval: 0.8320 to 0.9249) after 17 years (Fig 2).

Four (5.2%) of the 77 restorations placed in premolars and 17 (15.6%) of the 109 restorations placed in molars were rated as failures. In a univariate analysis that used the proportional hazards model, the molars proved to have significantly lower survival times than premolars (hazard ratio 3.11; $P = .041$) (Fig 3). With regard to the type of reconstruction, 3-surface inlays presented a higher risk than 1-surface inlays, although this did not reach statistical significance (hazard ratio 4.19; $P = .167$) (Fig 4). The 2- and 4-surface inlays and onlays did not differ from 1-surface inlays with regard to success/failure. With regard to gender (female/male), jaw (maxilla/mandible), or age group (< 40 years/> 40 years), no significant difference in the risk of failure was

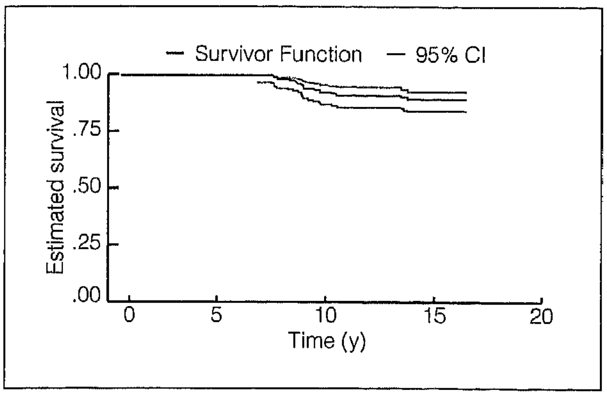


**Fig 2** Kaplan-Meier survival estimate for all restorations (n = 187; 21 failures).

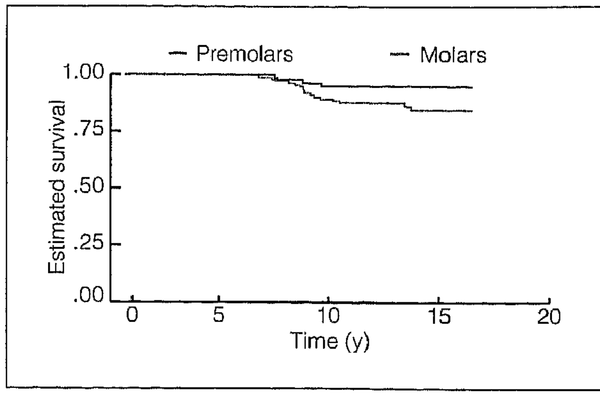


**Fig 3** Kaplan-Meier survival estimate with regard to tooth type.

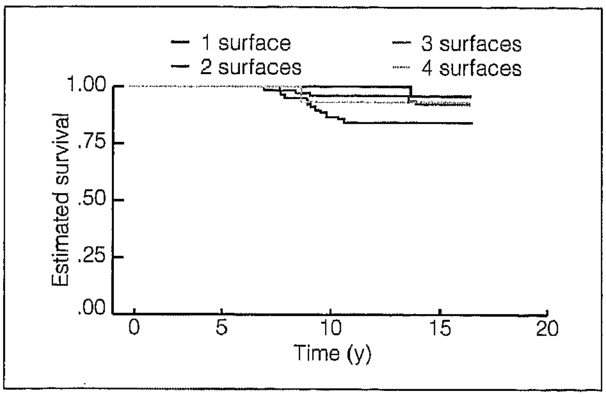


**Fig 4** Kaplan-Meier survival estimate with regard to number of surfaces.

seen. In a multivariate analysis that simultaneously controlled for all these variables, the hazard ratio for molars increased to 5.05 ($P = .006$) and the hazard ration for 3-surface inlays increased to 8.04, with borderline statistical significance ($P = .052$), whereas all other effects remained clearly statistically insignificant.

The most frequent reasons for the 21 failures were ceramic fracture (13 [62%] inlays and onlays) and fractured cusps of reconstructed teeth (3 [14%]; technical failures). Other reasons for failures were new caries (9.5%), secondary caries (9.5%), and endodontic problems (5%) (biologic failures) (Table 4). Two of the 3 patients with multiple failures presented with distinct bruxing habits. The failed restorations (21) were repaired with composite (10) or ceramic (1) or replaced with new Cerec restorations (7) or porcelain-fused-to-metal crowns (3) (Table 4).

## Discussion

After a follow-up period of up to 17 years, 94% of the restorations were reevaluated by a blinded examiner. Although the study design did not include control groups, the low dropout rate and the clear definition of a successful restoration permitted accurate assessment of the technique employed. The Kaplan-Meier survival rate of 187 inlays and onlays over 17 years was 88.7%. In 11 of the 21 inlays and onlays that were rated as failures, a simple repair with composite material or ceramic was possible, with the original Cerec restoration remaining in situ. Consequently, 10 (5%) of the 187 restorations had to be completely replaced during the 17-year observation period. Of these, 7 were reconstructed with new Cerec restorations, with the hard tooth tissue cut back only minimally. Only 3 (1.6%) of the teeth examined during the follow-up period had to be re-treated using an invasive method (a crown in these cases). This suggests that the initial defect-oriented, tooth structure-saving preparation permitted a good long-term prognosis. These favorable results are similar to those of other reports,[10-12] with a success probability of 84.4% after 18 years.[13]

It is of course impossible to compare these results to other, indirect ceramic reconstruction methods, since there are no studies available for such a period of time. However, comparison studies over 5 years[14,15] yielded similar results for various ceramic reconstruction methods, while long-term comparisons up to 15 years showed that ceramic inlays made out of prefabricated Cerec Mk I block-ceramic had a significantly higher survival rate than laboratory-fired ceramic inlays.[16,17] In

**Fig 5a** Ceramic fractures of the restorations (isthmus or chipping) accounted for 62% of failures.

**Fig 5b** Typical chipping fracture of the ceramic.

addition, few long-term clinical examinations are available for composite fillings or composite inlays, which have shown less favorable survival rates.[18,19]

The reported survival rates of gold cast inlays and onlays are similar to those seen in the present study: 96.1% after 10 years and 87% after 20 years[20]; survival rates of 97% at 9 years and 90.3% at 20 years were observed in a report carried out by a single practitioner.[21] Furthermore, this direct chairside approach does not involve a laboratory stage or fee and should therefore permit more cost-effective restorations.[22]

Fractures of the ceramic block accounted for 62% of the observed 21 failures. These results are compatible to those of other studies of Cerec inlays,[10–13] with ceramic fractures clearly outweighing other causes of failure.[14,15,17] In 2 cases, cusp fractures were seen, and in 1 case, a cusp suffered a fracture after endodontic treatment of the corresponding tooth. Other authors[13,16] showed significantly lower survival rates of Cerec inlays because of tooth fractures in nonvital teeth. In most cases, however, the fracture occurred at the (presumably) thinnest region of the inlay (isthmus fracture) or at the marginal ridge (chipping) (Fig 5). This could be a hint that in such reconstructions, a minimum thickness of the ceramic and the establishment of a proper occlusion should be respected.

The fact that 3 patients with multiple failures were diagnosed with bruxism suggests that this particular group of patients should be considered a higher-risk group with regard to Cerec restorations. This seems to be true for reconstructive materials in general.[23]

In only 2 cases was secondary caries 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.[24] This explains the slightly underfilled margins that could be found with a probe, but it does not seem to account for the occurrence of secondary caries. A change in the cementing gap of Cerec restorations, not accompanied by secondary caries lesions over a long-term period, was also found by other authors.[11,13] The consistent use of the adhesive technique for the placement of ceramic inlays and onlays with bonding composite[25] also seems to yield clinically sufficient results with the Cerec 1 method, where there are relatively large luting interfaces of up to 150 µm[24] and more.[26]

Statistically, the failure probability was slightly higher in the 3-surface Cerec inlays, but the differences in restoration failures with regard to the number of surfaces treated were not significant. This supports the idea that tooth structure should be conserved and preparations not extended for preventive reasons.

Restorations in premolars presented a significantly lower risk than those in molars. This result was also found in another study.[13] The analyzed data did not provide any conclusive evidence as to whether there were technical reasons for this, or whether this can be attributed to better accessibility for treatment or oral hygiene.

It must be emphasized that these results were observed in a much earlier version of the Cerec system's hardware and software protocols. Furthermore, they reflected the clinical performance of only 1 clinician, thereby limiting the conclusions that can be drawn from this report. However, the significant improvement in the product in recent years, combined with these reported experiences, suggests considerable promise for the technique, which is now also more user-friendly. Evidence of improvement in the accuracy of restoration fit[27] and a greater variety of possible preparation forms[28] also suggest better restorative prognoses. In addition to the feldspathic ceramic, different ceramic materials, including leucite-infiltrated glass ceramic and zirconia, have also been developed.[29] This may possibly enhance the strength of future restorations and their esthetic outcome. New models of automated CAD, such as biogeneric tooth reconstruction,[30] may also help in reconstruction of the occlusal morphology of teeth in specific clinical situations.

The results of this study must be interpreted in the context of the caveats referred to earlier. The technique clearly has enormous clinical potential since it offers the practitioner more control and ease in fabricating inlays, onlays, veneers, and even all-ceramic crowns with very acceptable esthetics.[31] It has also become easier to adjust the occlusion and screen the thickness of the ceramic, which may in turn help reduce the failure rate of ceramic restorations.

## Conclusion

The clinical survival rate probability of 88.7% after 17 years according to Kaplan-Meier makes Cerec CAD/CAM restorations made of Vita Mk I feldspathic ceramic acceptable in private practice.

## Acknowledgment

The authors would like to thank Dr Med Brian Martin, Evilard, for his kind assistance in the statistical analysis of the results.

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