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ORIGINAL ARTICLE

# Seven-year clinical performance of CEREC-2 all-ceramic CAD/CAM restorations placed within deeply destroyed teeth

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**Abstract**
*Objectives* Adhesively luted all-ceramic restorations represent a promising way to preserve and stabilize weakened tooth substance, but little information is published about the clinical performance of extensive all-ceramic restorations.
*Materials and methods* A total of 78 large CEREC 2™ single-tooth all-ceramic restorations had been placed in 35 patients. After 7 years, 59 teeth in 25 patients were reevaluated according to USPHS or modified USPHS criteria regarding aesthetic properties, e.g., "anatomic form," "color match," and "marginal discoloration"; functional properties, e.g., "marginal integrity," wear expressed by the criteria "proximal contact" and "static/dynamic occlusal relationship"; and biological properties, e.g., "tooth vitality" and "secondary caries". Additionally, the "proportion of margin below/above cemento-enamel junction" was included.
*Results* Two restorations had failed prior to the 7-year recall, one due to a bulk fracture of the restoration and one due to poor marginal integrity (rated "Charlie") after 4 years. Other six restorations were rated as failure at the 7-year evaluation (three restorations revealed secondary caries, one was bulk fracture of the Cerec 2 restoration, and two failures were related to endodontic problems resulting in extraction or amputation of one root, respectively), resulting in a failure rate of 13.1% after 7 years. A total of 96.4% of the restorations revealed sufficient ratings for esthetic properties "anatomic form," "color match," "marginal discoloration," and "marginal integrity".
*Conclusions* The survival rate of 86.9% at the 7-year recall demonstrates that adhesively luted all-ceramic CAD/CAM-generated restorations are suitable for restoration of extended coronal defects.

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*Clinical relevance* CAD/CAM-generated all-ceramic restorations facilitate the reconstruction of deeply destroyed teeth irrespectively of the location of the cavity margins.

**Keywords** All-ceramic restorations · CAD/CAM · CEREC 2 · Long-term performance

## Introduction

Tooth-colored all-ceramic restorations are more and more popular for restoring teeth due to good esthetics and biocompatibility. Adhesively luted all-ceramic restorations are able to stabilize remaining hard tissues [1]. Thus, preservation of residual coronal tooth substance of severely destroyed teeth is possible [2]. Bonded restorations are estimated as important alternatives to avoid conventional crowns requiring macro-mechanical, more destructive preparations [3]. Although there have been several clinical trials published regarding bonded all-ceramic inlays and onlays, only few clinical investigations report the performance of large all-ceramic restorations with proximal cavity margins below the cemento–enamel junction (CEJ) [4–8]. A study on the longevity of 2,328 all-ceramic inlay and onlay restorations reported that failures were mainly related to extractions [9]. A 10-year clinical study with Cerec inlays and onlays reported 73% of the failures having been related to ceramic fracture and 20% to tooth fracture [10]. Reasons for remaining failures were caries (20%) and endodontic problems (7%). Consequent inclusion of total bonding with dentin adhesives increased the success rates of Cerec inlays and onlays [11]. Restoration size did not affect long-term survival [11]. A 7-year study on Cerec partial crowns placed in posterior teeth revealed two fractures (4.8%), two restorations (4.7%) were rated "bravo" for marginal adaptation, and one restoration (2.4%) suffered recurrent caries [12]. A total of 75 Cerec all-ceramic partial crowns revealed only one bulk fracture [13]. Additional findings were no secondary caries, no hypersensitivity, and no critical wear occurred. A total of 19 Cerec endo-crowns revealed one failure after 28 months due to secondary caries [13]. Potential risks for ceramic fractures are related to bruxism and parafunctions [14], so bruxism generates up to six times higher loads on teeth and restorations [15].

The null hypothesis of the present study was that both extension of the restoration and location of proximal margins would have no influence on the clinical success of extended all-ceramic restorations.

For an investigation of all-ceramic restorations, the following five questions were addressed:

1. How did the machinable ceramics perform after 7 years?
2. How large was the portion below the CEJ and was it crucial for clinical success?
3. How important was additional macromechanical retention?
4. Was there an impact regarding the use of rubber dam?
5. What was the level of patient satisfaction?

## Materials and methods

The purpose of this study was to re-examine large CEREC 2 all-ceramic restorations after seven years of service according to the USPHS criteria. As large ceramic restorations, we defined restorations as that which at least replaced one cusp and half of the occlusal surface of a tooth by the ceramic restoration. After 7 years in clinical service, an analysis of the esthetic properties, functional properties, and biological properties of extended all-ceramic restorations was performed. Furthermore, it was of major interest to analyze whether the proportion of restoration margins below the CEJ influenced the clinical performance of the restorations. Additionally, the patients' contentment was evaluated. Besides a few conventional crowns, the majority of the teeth were restored by adhesively luted restorations since they were not done according to retentive requirements and the remaining tooth substance had to be stabilized by adhesive techniques. It was emphasized that all restorations were done as a substance-saving alternative to conventional crowns. The present study should answer the question if large all-ceramic restorations were suitable for the restoration of deeply destroyed teeth. Therefore, only teeth where at least half of the clinical crown had to be replaced were included. The application of the adhesive luting techniques using large all-ceramic restorations led to different preparation types.

### Patient selection

A patient's information sheet and informed consent form was prepared. A total of 78 restorations were originally inserted in 35 patients (25 male, 10 female, age 18–77 years) by one dentist in the Dental Clinic 2—Prosthetic Dentistry of the University of Erlangen-Nuremberg. Patients were informed that it was clinically necessary for quality control to re-evaluate the restorations after 7 years. The obtained data were made anonymous for statistical analysis and publication.

There were a total of 61 posterior teeth (78.2%) and 17 anterior teeth (21.8%) of patients who, based on their reliability to participate in the routine dental checkup of our dental clinic, were therefore included in the present study. Only teeth with extensive destruction of the clinical crown were included. At least one cusp and half of the occlusal surface had to be replaced. In case of a conventional

restoration, a metal or PFM crown or at least a full coverage metal onlay or crown would have been alternatives [16]. Impossible moisture control during restoration placement was reason for exclusion.

## Preparation

Prior to treatment, tooth color was determined with Vita-pan™ classical, the VITA Toothguide 3D-MASTER™ (Vita Zahnfabrik, Bad Säckingen, Germany) or the Chromascop™ Shadeguide (Ivoclar Vivadent, Ellwangen, Germany). Preparations were performed according to the recommendations of Mörmann [17]. Six classes of preparations (examples are shown in Fig. 1a–f) were applied [18]:

1. Onlay preparation. Restoration type: onlay (ON).
2. Classical crown preparation: circumferential shoulder width >1.2 mm. Restoration type: classical crown (CC).
3. Reduced crown preparation: after removal of caries, about half of the clinical crown remained; no additional core was build-up. Restoration type: reduced crown (RC).
4. The so-called endocrown preparation: the clinical crown was completely destroyed, the tooth was successfully endodontically treated, and the pulp chamber was used for additional macromechanical retention; no additional core build-up. Restoration type: endocrown (EC).
5. Veneer preparation. Restoration type: veneer (VE).
6. Implant crown (IC).

If necessary, an occlusal reduction of at least 1.5 mm of tooth substance was performed in order to achieve the required minimum thickness of the ceramic material of 1.5 mm. The distribution of types of teeth and their restorations is shown in Table 1.

## Impression and fabrication of the ceramic restorations

Using CEREC™ 2 (Sirona, Bensheim, Germany), treatment is possible chairside by taking an optical impression directly from the oral cavity with the CEREC™ camera or alternatively by taking the optical impression from a cast. We chose the alternative procedure due to time constraints in 47 cases. The scanning and manufacturing procedure were

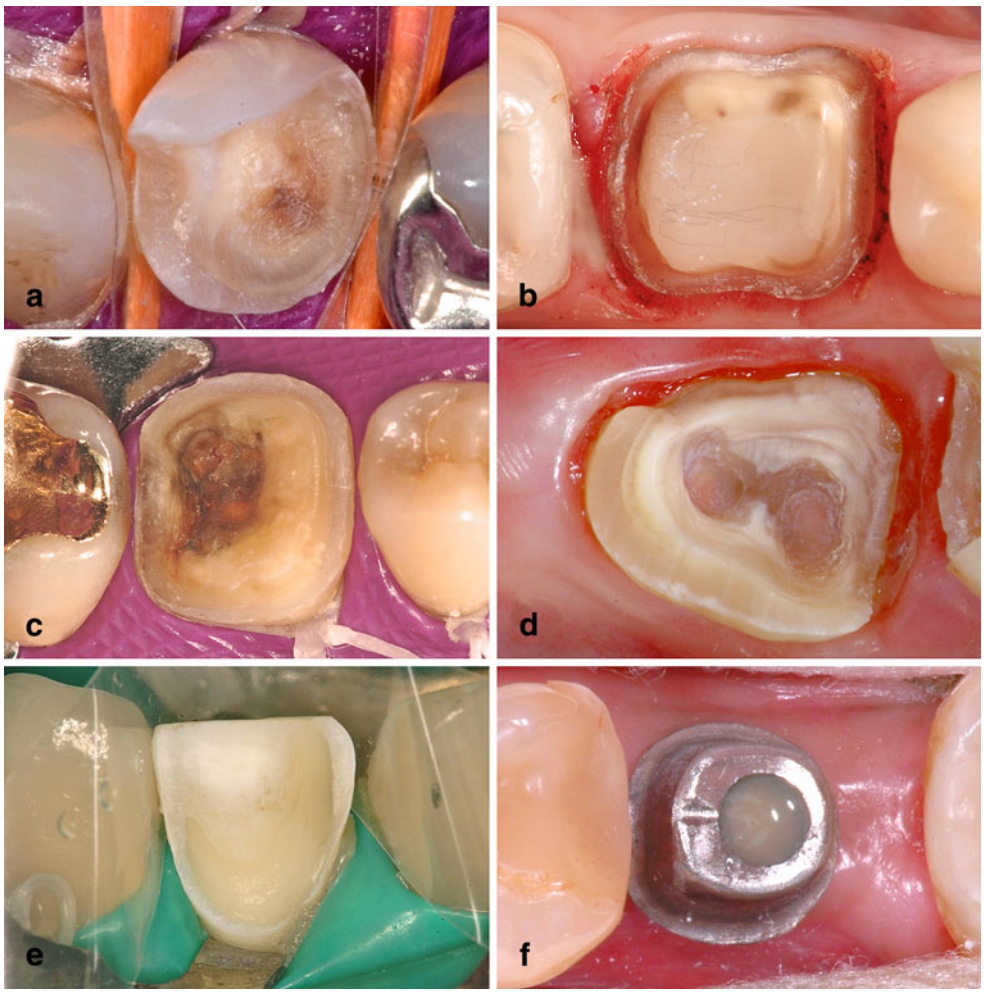


**Fig. 1** Example images of the cavity preparation for the six types of restorations (**a** onlay, **b** classical crown, **c** reduced crown, **d** endocrown, **e** veneer, **f** implant crown)

**Table 1** Distribution of restorations inserted at baseline and re-evaluated at 7-year recall

| Type of restoration | Tooth | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Restorations inserted (baseline) | | | | Restorations evaluated at 7-year recall | | | |
| | I | PM | M | Total | I | PM | M | Total |
| Onlay | 1 | 8 | 19 | 28 | 1 | 5 | 16 | 22 |
| Classical crown | 7 | 6 | 8 | 21 | 4 | 6 | 7 | 17 |
| Reduced crown | 0 | 1 | 3 | 4 | 0 | 0 | 2 | 2 |
| Endocrown | 0 | 0 | 12 | 12 | 0 | 0 | 11 | 11 |
| Veneer | 6 | 0 | 0 | 6 | 2 | 0 | 0 | 2 |
| Implant crown | 3 | 0 | 4 | 7 | 2 | 0 | 3 | 5 |
| Total | 17 | 15 | 46 | 78 | 9 | 11 | 39 | 59 |

described in detail by Reich and colleagues [19]. The virtually designed restorations were then ground from machinable ceramic blocks (VITABLOCS™ Mark II for CEREC™ (Vita Zahnfabrik, Bad Säckingen, Germany) or ProCAD™ (Ivoclar Vivadent, Schaan, Liechtenstein)) in the milling chamber of the CEREC™ 2 device. Prior to fitting, the maximum occluso-cervical heights of all restorations were measured with a caliper in order to identify what proportion of restorations exceeded 10 mm in height to see whether the CEREC™ 2 was capable of coping with such restorations. The finishing technique, as described by Arnetzl et al. was used for chairside as well as laboratory-fabricated restorations [20].

## Adhesive luting

The ceramic restorations were prepared as described by Reich et al. [19]. After etching the enamel with 35% phosphoric acid, the etch pattern was checked and at the same time the portion of enamel surrounding the preparation margin was determined by the operator. In order to create a clinically applicable determination, the whole preparation margin was defined as a circular figure of 360° and evaluated visually using a three-stage system (score 1, less than 50%; score 2, more than 50%; score 3, 100%) according to Reich et al. [19]. The remaining enamel was expressed in percentage of a circle of 360°. The determination of the preparation of the CEJ below or above was assessed clinically after etching with phosphoric acid.

As adhesive system for the dentine Syntac™ (Ivoclar Vivadent) and as luting composite, the light-curing Tetric™ Ceram ($n$=29) and the dual-curing Variolink™ Ultra ($n$=30) (both Ivoclar Vivadent) were used by applying the ultrasonic insertion technique [20].

Alternatively, the combination of cotton rolls and a retraction cord was used in cases where the rubber dam could not be placed. After insertion, static and dynamic occlusal relationships were checked. Dynamic working contacts were accepted if they matched those present prior to treatment.

## Evaluation of the restorations

In order to avoid any bias, the operator (S.R.) and the evaluators (M.R., B.K.) were different individuals. The restorations were investigated independently by two experienced, calibrated examiners trained and familiar in the clinical evaluation of direct and indirect restorations for at least 8 years. Esthetic properties, e.g., "anatomic form," "color match," and "marginal discoloration," were evaluated according to the USPHS criteria. Functional properties were rated according to USPHS ("marginal integrity") or modified USPHS criteria ("proximal contact" and "static/dynamic occlusal relationships") according to [3]. The biological properties "tooth vitality" (assessed with carbon dioxide) and "secondary caries" (inspected visually) were monitored throughout the study [21, 22]. Consistent ratings were obtained in 88.6% of all ratings (Cohen´s kappa, 0.72). In cases with different values, the average rating was used for statistics. Additionally, in cases where a restoration was rated as not sufficient, the decision to replace it was made by a further investigator (R.F.). The 3-year results of this study were published previously [19].

## Statistical analysis

The statistical analysis was computed with SPSS™ for Windows™ 14.0 (SPSS Inc., Chicago, IL, USA). All factors of influence on the results were studied. The survival rates were computed with Kaplan–Meier analysis method. Non-parametric tests were performed for pairwise comparisons among groups. Kruskal–Wallis test and Mann–Whitney $U$-test were computed for the functional properties "marginal integrity" and "proximal contacts." The effect of the "proportion of the margin" was computed with Kruskal–Wallis test, and its effect on proximal contact was computed with Spearman correlation. Wilcoxon signed rank test was used for analysis of the esthetic properties "anatomic form," "color match," and "marginal discoloration," the functional properties "static/dynamic occlusion," and the biological properties "tooth

vitality" and "secondary caries." Data were computed with chi-square test. The confidence level was set to 95% ($p<0.05$).

## Results

A total of 78 restorations were originally inserted in 35 patients. The patients' age ranged from 21 to 80 years with a mean age of 52 years. The number of restorations per patient ranged from 1 to 8 (eight restorations were placed only in one patient) with an average of two restorations per patient. In the 7-year follow-up, 59 of the restorations, placed in 25 patients (17 male, 8 female), were investigated. The restorations were investigated and re-evaluated after an average time of 84 months (±6 months) of clinical service. A total of 39 restorations were inserted in molars, 11 in premolars, and 9 in incisors and canines. Most restorations evaluated after 7 years were onlays ($n=22$) and classical crowns ($n=17$). Additionally, two reduced crowns were inserted in molars. Eleven endocrowns were inserted in the molar region. Four classical crowns and two veneers were inserted in anterior teeth. Two implant crowns were inserted in the anterior region and three in the molar region (Table 1). The chairside method was used 8 times out of 59. Most of the onlays (19 out of 22) were inserted by using rubber dam. With 10 out of 18 crowns inserted, the application of rubber dam was not possible. Six out of ten endocrowns had to be luted without rubber dam. Unfortunately, ten patients were not available anymore because they moved to another location. Thus, 19 restorations that were inserted initially could not be included in this study.

### Clinical evaluation

Table 2 shows modified USPHS criteria. The results of the clinical examination after 7 years according to the esthetic properties "anatomic form," "color match," and "marginal discoloration," the functional properties "marginal integrity," "proximal contact," and "static and dynamic occlusal relationships," and the biological properties "tooth vitality" and "secondary caries" are also presented (see Table 3).

### Clinical success and reasons for failures

Figures 3 and 4 show an all-ceramic CEREC™ 2 restoration after 7 years in clinical service. In total, two bulk fractures, two endodontic problems, the recurrent carious lesions, and one non-sufficient margin were the reasons for failure. Thus, a total number of eight failures resulted in a clinical success rate of 86.9% (see Fig. 2). Two restorations had failed prior to the 7-year recall, one due to bulk fracture of the all-ceramic restoration and one due to poor marginal integrity (rated "Charlie"). One molar, already endodontically treated prior to inclusion in the study, had to be treated by amputation of the mesial root due to a large periapical lesion caused by longitudinal fracture of the mesial root. This all-ceramic restoration had to be replaced by a conventional fixed dental prosthesis (bridge). Another endodontically treated tooth had to be extracted due to endodontic problems with a large periapical lesion and no alternative treatment option. One inlay restoration inserted in one patient who developed severe bruxism, in the meantime, revealed a fracture and was replaced by a conventional crown. The three other failures were related to secondary caries in the proximal region. None of the other remaining restorations showed signs of fracture of both ceramic and tooth structure.

### Clinical findings

#### *Esthetic properties—anatomic form, color match, and marginal discoloration*

The anatomic form of the restorations was rated "Alfa" in 41 cases (69.5%) and "Bravo" in 14 cases (23.7%), while one restoration (1.7%) was rated "Charlie."

In terms of color match, 46 (78%) restorations were rated "Alfa," 9 (15.2%) restorations were rated "Bravo," and one restoration (1.7%) was rated "Charlie."

Marginal discoloration was rated "Alfa" in 34 cases (57.6%) and "Bravo" in 22 cases (37.3%) (Table 3). The statistical analysis showed that the percentage of residual enamel did not reveal any effect on marginal discoloration (Kruskal–Wallis test, $p>0.05$).

#### *Functional properties—marginal integrity, proximal contact, and static/dynamic occlusion*

Marginal integrity was rated "Alfa" in 39 cases (66.1%) and "Bravo" in 17 cases (28.8%) (Table 3). Shaded and glazed restorations yielded significant weaker results in respect of "marginal integrity" (Mann–Whitney test, $p=0.013$). The statistical analysis showed that the percentage of residual enamel did not reveal any effect on marginal integrity (Kruskal–Wallis test, $p>0.05$).

A total of 16 restorations (27.1%) revealed a much too weak proximal contact (rating "3") but without showing food impaction. Therefore, these restorations were not rated as failures due to the fact that no re-restoration was necessary in any case.

The static and dynamic occlusion revealed significantly weaker results for RC and CC compared to the other restoration types (Kruskal–Wallis test, $p=0.016$).

#### *Biological properties—tooth vitality and secondary caries*

None of the patients re-examined at the 7-year follow-up described discomfort or pain during percussion test. None of

**Table 2** Modified USPHS criteria for the clinical evaluation of the restorations

| Characteristic | Rating | Criteria |
|---|---|---|
| Marginal integrity | Alfa | No visible evidence of ditching along the margin |
| | Bravo | Visible evidence of ditching along the margin not extending to the DE junction |
| | Charlie | Dentin or base is exposed along the margin |
| | Delta | Restoration is mobile, fractured, or missing |
| Anatomic form | Alfa | Correct contour. The restoration is contiguous with tooth anatomy |
| | Bravo | Slightly under- or overcontoured restoration |
| | Charlie | Distinctly under- or overcontoured |
| Secondary caries | Alfa | No evidence of caries contiguous with the margin of the restoration |
| | Bravo | Caries contiguous with the margin of the restoration |
| Color match | Oscar | Restoration cannot be detected with a mirror |
| | Alfa | No mismatch in color, shade, and translucency between restoration and adjacent tooth structure |
| | Bravo | Mismatch between restoration and tooth structure within the normal range |
| | Charlie | Mismatch between restoration and tooth structure outside the normal range of color, shade, and translucency |
| Marginal discoloration | Alfa | No discoloration on the margin between the restoration and the tooth structure |
| | Bravo | Discoloration on the margin between the restoration and the tooth structure |
| | Charlie | Discoloration has penetrated along the margin of the restorative material in a pulpal direction |
| Proximal contact | 1 | Strong contact, metal matrix (~ 50 μm) goes through under pressure |
| | 2a | Too weak, metal matrix goes through without resistance |
| | 2b | Too strong, metal matrix cannot be forced through the proximal contact area |
| | 3 | Much too weak, but no complaints and no indication of trauma to the adjacent gingivae |
| | 4 | Food impaction, restoration must be replaced |
| Static/dynamic occlusal relationships | 1 | Stable intercuspal position, satisfactory anterior guidance with immediate disclusion |
| | 2 | Stable intercuspal position, Acceptable anterior guidance with disclusion. Dynamic occlusion is oriented on the entire dynamic occlusion pattern, if canine guided no other working contacts simultaneous, regular and equilateral static occlusion, no damaging or primary contacts in dynamic occlusion |
| | 3 | Unstable intercuspal occlusal relationships, weak centric stops on restored tooth or incline contacts rather than axial loading. Restoration needs regular observation |
| | 4 | The restoration has to be replaced due to non-functional anatomy |

the teeth showed hypersensitivity or had to pass endodontic treatment during the study. Three restorations were rated "Bravo" for secondary caries in the proximal region.

*Design-related factors—proportion of the restoration margin and height of the restoration*

The relationship between the findings for the USPHS criteria and the proportion of restoration margin remaining in enamel is shown in Table 6. In 17 cases, more than 50% of the finish line of the preparation was located below the cemento–enamel junction. Restorations with less remaining enamel revealed weaker proximal contacts (Spearman correlation test, $\rho = 0.351$; $p=0.014$). Increased occlusal height of the restorations had a significantly negative influence on the outcome of the proximal contact and the anatomic shape of the restorations (Kruskal–Wallis test, $p< 0.01$).

## Additional findings

*Level of patients' contentment*

Based on the scoring system that was presented in a previous study [19], 21 out of 25 patients responded that they were very content with their restorations, and three patients were

**Table 3** Results of clinical investigation after 7 years (±0.5 years) (rating according to USPHS criteria)

| Number (%) of restorations at 7-year recall (total *N*=59) | | | | | |
|---|---|---|---|---|---|
| Rating | Marginal integrity | Anatomic form | Secondary caries | Color match | Marginal discoloration |
| Oscar[a] | | | | 0 | |
| Alfa | 39 (66.1) | 41 (69.5) | 48 (81.3) | 46 (78.0) | 34 (57.6) |
| Bravo | 17 (28.8) | 14 (23.7) | 3 (5.1) | 9 (15.2) | 22 (37.3) |
| Charlie | 0 (0) | 1 (1.7) | | 1 (1.7) | 0 (0) |
| Delta[b] | 0 | | | | |
| N. p.[c] | 0 (0) | 0 (0) | 5 (8.5) | 0 (0) | 0 (0) |
| N. p.[d] | 3 (5.1) | 3 (5.1) | 3 (5.1) | 3 (5.1) | 3 (5.1) |
| Total | 59 (100) | 59 (100) | 59 (100) | 59 (100) | 59 (100) |

[a] Only available for the criterion "color match" (according to Ernst et al. [46])

[b] Only available for the criterion "marginal integrity"

[c] No ranking possible because of implant abutment

[d] No ranking possible, because of replacement of original restoration prior to 7-yr recall

content with their restorations. The demented patient was unable to express his level of contentment.

*Luting procedure*

The luting composite (Variolink II or Tetric) as well as the extension of the restoration according to the Mörmann classification [17] did not affect the outcome of the study ($p>0.05$). Variolink, due to its dual-curing properties, was used in extremely deep cavities like for endocrowns, where exclusive light polymerisation in deep areas was debatable. Rubber dam was placed when possible. The two different luting composites did not display any differences in terms of marginal discoloration ($p>0.05$). Furthermore, according to

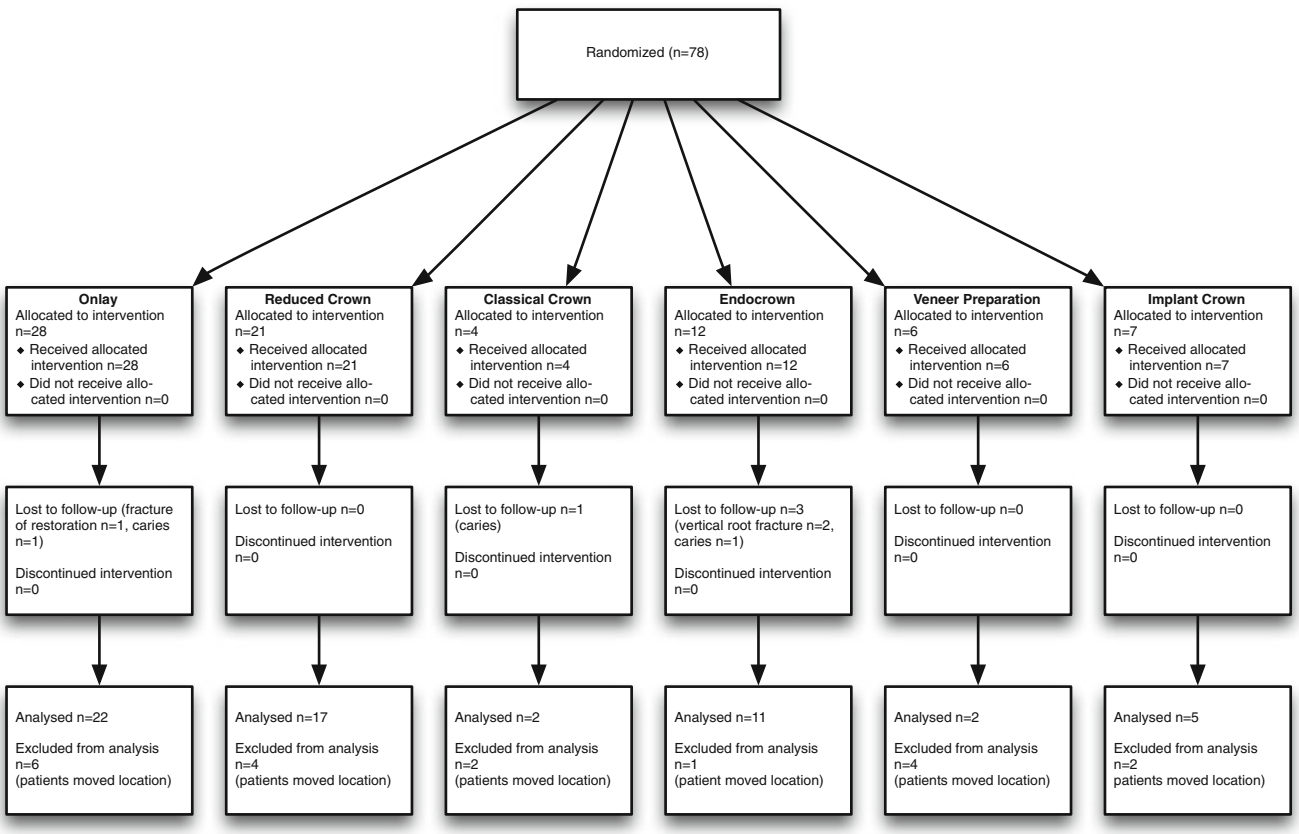


**Fig. 2** Flow diagram of the study design according to CONSORT statement

marginal discoloration and secondary caries, no significant differences ($p>0.05$) were observed regarding the use of a rubber dam.

## Discussion

In the introduction section, we posed five questions that are discussed below:

1. Performance of machinable ceramics after 7 years

Regarding the fact that this study included only extended all-ceramic restorations, their performance was satisfactory. This finding is in agreement with other studies evaluating the performance of less or more extended all-ceramic restorations showing survival rates between 85.7% to 90.6% after follow-up periods from 5.5 to 10 years [23–25]. Regarding the nature of failure, there was only one restoration that was lost due to fracture of the ceramic restoration caused by bruxism. The other failures, e.g., endodontic problems or secondary caries, have to be addressed to weakened root dentine or insufficient oral hygiene that also can affect the success of other types of restorations and does not represent a finding that is specifically related to all-ceramic restorations. Other studies revealed that bulk fractures were the predominant failure mode [26, 27]. This is in agreement with the present study.

In order to test the limitations of the adhesive luting technique and the CAD/CAM system, predominantly severely decayed teeth were included in this retrospective study. Due to several reasons, only 25 out of 35 patients were available for the 7-year follow-up (recall rate, 71.4%). Thus, 59 out of 78 restorations inserted at baseline (75.6 %) were investigated in the present study. Probably, the screening of patients that were included in the present study was not strict enough in order to exclude potential non-participants prior to the start of this study. Regarding the distribution of teeth, the number of incisors was small. Due to the fact that long-term data of either all-ceramic restorations are rare, we decided to include restorations in anterior teeth, although it revealed inhomogeneous distribution as the result of long-term evaluation, and to discuss the inability to draw conclusions. However, it is of certain value though to present the data, and all restorations fulfilled the demands of this study due to the fact that besides extended restoration design, proximal and static/dynamic occlusal contacts were mandatory.

The authors of this study are aware of the recommendations of Hickel et al. to conduct clinical studies [22]. At the time when this study was initiated, these recommendations were not available. Criteria for participation in this study were adequate oral hygiene with little or no caries risk and absence of bruxism or habits. However, the patients included in this study were selected carefully in order to fulfill the conditions of participation in this study.

### Clinical outcome and comparisons to other studies

Regarding the null hypothesis, we found that neither the extension of all-ceramic restoration nor the location of the margins did significantly affect the outcome of the clinical result. Thus, both parts of the null hypothesis were not rejected.

With respect to these conditions, the results for extended all-ceramic restorations presented in this study (success rate after 7 years, 86.9%) are encouraging. Several studies reported results after an observation time of 3 to 6 years [2, 25, 27–29]. The results of the present 7-year follow-up are comparable to the results of other studies investigating adhesively luted inlay and onlay systems under less extreme conditions [2, 5–8, 23, 28]. Krämer et al. reported that 8 out of 96 restorations failed during an observation period of 8 years [30]. Reiss investigated 1,011 all-ceramic restorations inserted in 299 patients over a mean observation time of 16 years with a total of 86 failures [31]. Mostly ($n=989$), feldspathic blocks provided by the Vita Company were used [11]. There were no differences in terms of failure rate in relation to the size of the restorations. Fractures represented the most frequent reason for failure [26].

However, none of these studies was only focused on large restorations. Due to the fact that the latter studies comprised inlays and onlays, the comparability to the present study is limited.

A study of Felden et al. (1998) retrospectively observed 232 inlays and 55 partial crowns and calculated the probability of survival for 7 years [2]. Whereas they revealed a survival of 98% for the inlay group, the probability of survival was 56% for partial crowns. Thirteen out of fourteen of the failed partial crowns were made of Dicor™ glassy ceramics. The authors recommended further experiences with more recent ceramics.

In the current investigation, exclusively focused on large restorations, only two bulk fractures (3.4%) occurred during the 7-year follow-up, which is in agreement with other studies that reported fractures between 0% and 6.3% [23–26]. Thus, the present study showed that the adhesively luted ceramic materials used here were reliable to restore even extended cavities sufficiently.

### Clinical failures of restorations

In total, eight failures occurred up to the 7-year follow-up. All failures were long-term failures according to Hickel et al. [21]. Two failures already occurred at 3-year follow-up [19]. Other six failures occurred at 7-year follow-up, three failures with regard to secondary caries. One patient, who

showed recurrent caries on two out of eight restorations, was not able to improve his oral hygiene within the last years although no shortcomings in terms of oral hygiene were visible during patient selection. Another restoration in a mandibular molar of a patient who became demented in the meantime with deficiencies regarding his oral hygiene was repaired with composite but was rated as failure. None of the failures could be contributed to deficiencies of the restorations. The other three failures that required a replacement of the all-ceramic restorations prior to the 7-year recall were related to bruxism (not present at baseline) or endodontic problems. Therefore, these failures were not related to deficiencies of the restorations themselves.

This study confirmed that even severely decayed teeth were successfully restored whilst preserving natural tooth substance as indicated by the preponderance of onlay restoration (Fig. 3).

A 7-year survival rate of 86.9% is satisfactory and comparable with other studies or superior that reported survival rates of 56% to 84% for onlays and partial crowns and 89% to 98% for inlays [2, 12, 31–33]. Crowns were only inserted if old crown restorations had to be replaced or extensive occlusal and cervical defects coincided.

Operators' influence

Due to the fact that the preparation of the cavities, the design of the restoration, and the insertion of the restorations were all performed by the same well-experienced operator (S.R.), any operator influence on the outcome of this study was excluded.

Luting procedure

A careful adhesive luting procedure is therefore responsible for the long-term success of all-ceramic restorations [30].

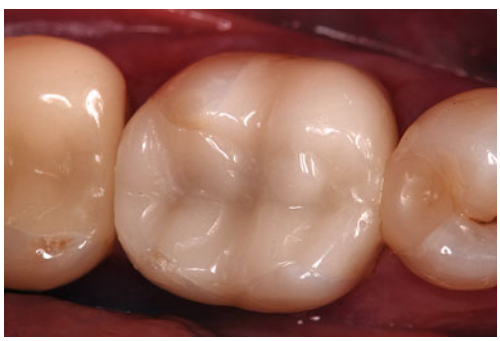

**Fig. 3** Onlay restoration 7 years after placement on a vital lower left first molar. The extended restoration was fabricated chairside using the CAD/CAM manufacturing system CEREC 2 (Sirona Dental Systems GmbH, Bensheim, Germany)

The removal of the smear layer during the insertion of the restorations with acids seems to be an essential step in the placement of adhesively luted all-ceramic restorations [34]. Regarding the bonding system, the application of a multi-step adhesive system may be responsible for the absence of postoperative sensitivity. This can be explained by the content of glutaraldehyde in the DBA system or the little shrinkage of the resulting resin cement film [35]. In the present study, only Syntac as a well-established bonding system was used.

Regarding the preparation itself, no significant influence of the extension of the restoration on the clinical result could be observed. The failures observed in the present study were not associated to the adhesive luting materials. Thus, all-ceramic Cerec inlays did not incorporate a higher risk of failure compared with less extended all-ceramic restorations.

Hybrid-type fine-particle composites were used for luting due to their material properties as well as their wear behavior being superior to other materials [36]. The restorations were inserted with Tetric or Variolink, depending on the extension of the restoration and the depth of the cavity.

Correct adhesive luting without rubber dam is very time consuming and has therefore to be pondered against methods and restorations where conventional cementation techniques can be applied. Self-adhesive resin composites in combination with feldspathic materials may be an alternative to the well-established adhesive techniques, but there is still some lack of long-term data [37, 38]. However, the luting agents used in the present study did not reveal any significant influence.

2. Influence of the portion below the CEJ on clinical performance

Statistically, the location of the margin above or below the CEJ did not affect significantly the clinical outcome of all-ceramic restorations. Thus, the location of the cavity margin below the CEJ due to serious decay is no disadvantage per se. In fact, the extension of the restoration had no effect on the long-term success. These findings are supported by other authors who reported that neither the size nor the type of the restoration influenced the survival rate [11, 25, 31]. However, as long as sufficiently dry conditions during the luting process can be performed, the presence of enamel margins is not associated with better clinical performance of all-ceramic restorations.

The extension of the restoration was a relevant factor for the quality of the proximal contacts. In general, less remaining enamel and increased occlusal height of the restoration were associated with weaker proximal

**Fig. 4** The mesio-buccal cusp of the mandibular molar was replaced by the CEREC onlay. No sign of crack formation, secondary caries, or discoloration of the margin was observed

contacts of the restoration. In 16 cases, the proximal contacts were much too weak. Due to the fact that there were no problems recorded with respect to food impaction and patients' complaints, the rating had no clinical consequence. An explanation for this finding may be that restorations with less remaining enamel were more difficult to design and subsequently may have negatively affected the initial proximal design of those restorations. The more complex the design was, the more difficult was the virtual design of the proximal region. Meanwhile, the CEREC™ method has been turned from a two-dimensional design to a 3-D-mode with Microsoft Windows™ user interface. Additionally, many software features have been implemented that make the design of proximal and occlusal form easier and more precise [39, 40].

3. Importance of additional macro-mechanical retention

Regarding the results of the present study, it can be observed that even restorations that revealed almost no macro-mechanical retention, e.g., veneers or onlays with cusp

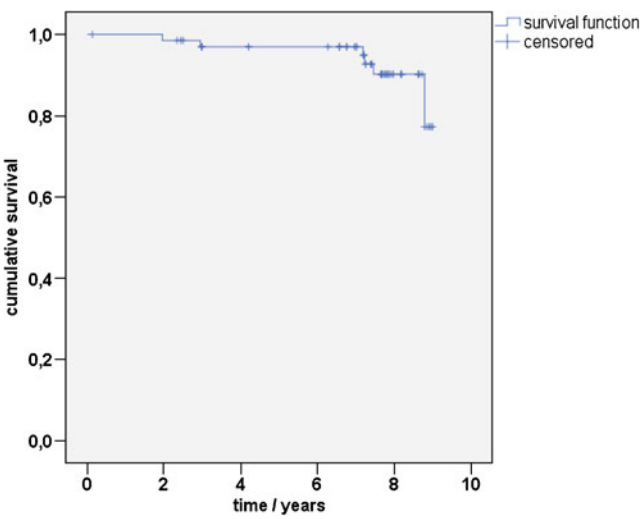


**Fig. 5** Kaplan–Meier cumulative survival rate of large CEREC all-ceramic restorations. The drop under 0.8 after 8 years is caused by low sample size

replacement, performed satisfactorily. In no case any loss of retention due to failure of adhesive luting was observed. Thus, adhesive luting may be seen as a sufficient procedure for the long-term placement of tooth-colored machinable all-ceramic restorations in deeply destroyed teeth. In 1992, Mörmann and Krejci already found that adhesively luted ceramic restorations were able to withstand occlusal loads for years if they were adhesively luted [41]. In consequence, Krejci mentioned that in adhesive systems the macro-mechanical retention has been substituted by adhesive luting to dentine [42]. This has been supported by the findings of Reiss and Walther who demonstrated that the extension of all-ceramic restorations did not affect their success rate [11]. Regarding veneer restorations, Castelnuovo et al. stated that all-ceramic restorations were dependent on adhesive luting instead of macro-mechanical retention [43]. These studies support the findings of the present study that extended all-ceramic restorations performed satisfactorily even though macro-mechanical retention is reduced or completely absent.

4. Impact of using rubber dam

According to the results of the present study, there is no impact of the use of rubber dam. In the event of the omission of rubber dam, it is far more difficult to keep control over the elimination of humidity over the whole luting procedure. However, within the limits of the present investigation, the application of rubber dam does not seem to be decisive for success. These findings are supported by a study of Thordrup et al. who mentioned that the need for rubber dam use could be questioned [44].

5. Level of patient satisfaction

The high success rate of extended Cerec-2 all-ceramic restorations was a main factor for high patient contentment. None of the patients felt discomfort with the restoration or would reject any further treatment with this method. In contrast, all patients were very satisfied, especially those who got their treatment finished within one appointment. Luting of CEREC restorations with the described previously luting technique avoided sufficiently the occurrence of post-operative hypersensitivities. This resulted in high acceptance and contentment of those restorations. All patients were contented (three patients) or very contented with the ceramic restorations, including those patients where restorations had failed (Figs. 4 and 5).

## Conclusion

CEREC™ 2 CAD/CAM restorations re-evaluated in the present study performed satisfactorily for the restoration of

extensive defects. The annual failure rate of 1.9% over an observation time of 7 years was comparable to other studies [24, 25, 45]. In agreement with Reiss, the clinical success rate was hardly affected by location and extension of the restoration as well as macromechanical retention [31]. However, the level of patients' compliance at 7-year recall was higher than expected. As stated by other studies, extended all-ceramic CAD/CAM restorations provide successful restoration of posterior teeth [2, 12, 45].

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**Conflicts of interest** All authors declare that they have no conflicts of interest.

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