# 10-Year Clinical Comparative Study of Ceramic and Composite Veneered Metal Crowns


## Keywords

*Mechanical Complications*
*Fixed Partial Dentures*
*Composite Veneerings*
*Ceramic Veneerings*
*Discolorations*
*Periodontal Parameter*



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## ABSTRACT

*The rejection of composite veneerings in fixed partial dentures is primarily caused by the inadequacy of the bonds between the metal framework and the composite veneering. The development of improved veneering composites necessitates an investigation of their clinical suitability compared with ceramic materials. Nineteen patients with at least two suitable, adjacent natural teeth for crowning were treated with 64 high noble alloy crowns. The adjacent crowns were veneered with ceramic (IPS inline) and composite materials (SR Adoro). Seven follow-up examinations were carried out over a period of 10 years. The crowns were investigated for mechanical defects, periodontal parameters, and discolorations. The survival rates of the ceramic veneered metal crowns (CeMCs) and composite veneered metal crowns (CoMCs) at the 10-year follow-up were 87.1 and 87.9%, respectively. The success rates of the crowns after 10 years were 83.9% for CeMCs and 51.5% for CoMCs (log-rank test, $p = 0.009$). No significant differences between the groups were found in the periodontal parameters (Kruskal–Wallis one-way analysis of variance, ANOVA $p > 0.05$). After 10 years, discoloration patterns of the two materials differed significantly (Mann-Whitney-U-test, $p = 0.017$). Thus, despite the improvements associated with CoMCs, CeMCs remain the gold standard for veneered metal crowns.*


## INTRODUCTION

Composite-veneered fixed partial dentures are of interest as an alternative to ceramic-veneered restorations owing to their uncomplicated handling, good aesthetics, and simplicity of repair. The rejection of composite veneerings in fixed partial dentures has been primarily attributed to a) the inadequacy of the bond between the metal framework and the composite veneering and b) the resulting mechanical defects and marginal gaps. Improved mechanical[1] and chemical[2,3] bonds to the metal framework have led to the need to investigate the clinical suitability of the newly developed composites as veneering materials. Furthermore, modern composites have been modified in regard to the components and proportions of their fillers, matrix compositions, and filler–matrix compounds. As a result, they are now distinguished by their improved mechanical properties with regard to abrasion resistance,[4] color stability,[5] and hygienic properties.



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The veneering composite "SR Adoro" was investigated in various *in vitro* studies. Urethane dimethacrylate (UDMA) matrix was found to be hydrolytically stable with very good mechanical performance.[6] Polymerization of the composite in the presence of heat and increased pressure results in further improvements to its mechanical properties.[7]

In general, composites are characterized by increased elasticity, which is advantageous for the absorption of strong chewing forces.[3,8] Additionally, the veneering of metal frameworks with composites requires less work and time, is more cost-effective, and can be fabricated without additional special instructions. However, ceramic materials are considered the gold standard materials for veneering metal frameworks because of their outstanding optical properties, low-plaque accumulation, and low-discoloration tendency. Despite these advantages, there are the disadvantages of possible chipping due to their increased brittleness,[8] the increased amount of work and time required, and the complicated handling during processing. Up to now no clinical studies had existed on the long-term behaviors of composite veneered metal crowns (CoMCs) in comparison to ceramic veneered metal crowns (CeMCs).

To test the hypothesis that composite veneerings in fixed partial dentures yielded comparable responses to ceramic veneerings in terms of mechanical defects, color stability, and hygienic properties, metallic crown frameworks with both ceramic and composite veneerings were investigated in a long-term clinical study based on constant oral conditions during a 10-year wear period. Accordingly, it was postulated that the veneering material types would show no differences.

# MATERIALS AND METHODS

The study was conducted between May 2006 and November 2017. The protocols were approved by the ethics committee of the medical faculty at the Martin-Luther-University Halle-Wittenberg (Ref. -Nr. 164/12.10.05/7) and conducted in accordance with the Declaration of Helsinki on Ethical Principles for Medical Research. Patients who had at least two suitable adjacent natural teeth that were intended to be restored with single crowns—owing to extensive defects—were offered the opportunity to participate in the study. After the verbal and written explanations by the responsible dentist, formal written informed consent was required and obtained from all participants. Participation criteria included a minimum age of 18 years, a high standard of oral hygiene, periodontal stability, and an appropriate dental restoration pretreatment. Excluded from the study were patients with a past or present history of chemotherapy or radiation, patients who were scheduled for chemotherapy or radiation, and patients with anamnestic parafunctions.

All patients had at least two adjacent teeth that were intended to be restored with single crowns. The type of veneering material was selected randomly. A caries-free, natural, vital tooth was selected as the reference tooth that corresponded to the same tooth type on the opposite side of the same jaw. If this was not possible, the same tooth on the opposing jaw was considered as the reference tooth. Patients were informed about the procedure of the clinical trial. If the patients chose to participate in the study, they underwent a comprehensive preliminary dental examination. If necessary, periodontal and/or conservative dental pretreatment was carried out.

## INSERTION OF CROWNS

The teeth included in the study were prepared to achieve a chamfer finishing line with the dimensions required for a complete veneered single crown and a taper ≤ 6°. A supragingival preparation position where previous restoration or filling margins existed was preferred, and compliance with aesthetic standards was ensured. A conventional impression was performed with an individual impression tray using polyether (Impregum/Permadyne) and the double-mix impression technique. The metal framework was then fabricated. Two different alloys with high gold content were used: IPS d.SIGN was used for the CeMCs and Academy Gold was used for the CoMCs. As part of the clinical framework evaluation, the marginal fit was examined based on the use of a dental probe. A thin-flowing silicone (Fit Checker) was used to check the internal fit on the prepared tooth. The crowns were veneered in the dental laboratory in compliance with the manufacturer's specifications. A leucite ceramic (IPS InLine,) was used for CeMCs, and a microfiller composite (SR Adoro) was used for the CoMCs. After the technical completion of the crowns, they were rechecked for their marginal and internal fits in the patient. The proximal and antagonist contacts were inspected with occlusion or shimstock foil and were adjusted if required. Subsequently, complete polishing cycles were carried out. The internal surface of the finished crown that was adapted to the patient was cleaned and roughened by air-abrading with aluminum oxide. The crowns were fixed with self-adhesive composite cement. The residues were removed after the completion of the proper hardening process of the material.

## FOLLOW-UP EXAMINATIONS

Follow-up examinations were carried out between May 2006 and November 2017. They were scheduled to occur after 14 days (baseline), 6 months, 18 months, 30 months, 42 months, and 10 years following the initial crown placement. Within the scope of the follow-up examinations, the following findings were documented in accordance with the study protocol. It was noted in the protocol whether the crown was still sufficiently in place at the time of the examination. Extracted teeth or teeth with renewed crowns were excluded from the number of survival crowns. Teeth with an access cavity for root canal treatment were noted with "biological complications". If the crown and its veneering were sufficiently in situ after the preparation of the access cavity, it was left in the study population. These cases and all cases without complications were noted as "survival". Restorations were examined visually and with the help



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of a probe for the existence of defects. Occurring defects were classified according to the procedure described by Heintze and Rousson.[9] A distinction was made as follows:[9]

Grade 1 = small chipping of the veneering, which could be corrected by polishing

Grade 2 = moderate chipping of the veneering with a loss of substance that could be corrected by a composite repair

Grade 3 = serious chipping of the veneering that required removal of the crown was equivalent to the technical complication in our classification.

Success of the examined crown was assumed if the crown was in situ without mechanical defect at the time of examination. The sulcus bleeding index (SBI) was determined for crowned teeth and their corresponding reference teeth. There were five categories based on the index of Muhlemann[10] *(Table 1)*.

**Table 1.** Classification of the sulcus bleeding index (SBI)[9]

| Category | Criteria |
|---|---|
| 0 | No bleeding |
| 1 | Only one bleeding point present |
| 2 | Several isolated bleeding points with a small volume of blood |
| 3 | Interdental triangle filled with blood |
| 4 | Profuse bleeding spreading toward the marginal gingival |

Six-point measurements of probing depths and periodontal recessions were performed on each tooth. The highest value was noted. Prior to shade measurement, professional tooth cleaning was performed. A spectrophotometer (Vita Easyshade Compact, VITA Zahnfabrik, Bad Säckingen, Germany) was used to measure the shade properties. For reproducible positioning of the measurement head during follow-up evaluations, deep-drawing splints were designed for each patient. These had openings in the central area of the vestibular surface, which corresponded to the size of the measurement head. In order to verify the color difference (ΔE) of the veneerings in the CIELAB color space, the values of luminance (L), red-green-axis (a), blue-yellow-axis (b), chroma (c), and hue (h), were measured and documented.

## STATISTICAL ANALYSES

Statistical evaluation was conducted using SPSS 22.0 (IBM, Armonk, New York, USA). First, the normal distribution of the data was checked for each comparison between the groups by the Kolmogorov-Smirnov test. In the case of normal distribution, one-factor variance analysis or Pillai's trace was performed. Non-parametric tests performed in cases of no normal distribution were the Kruskal-Wallis-test and Friedman test.

The survival rates of CeMCs and CoMCs were estimated by the Kaplan-Meier-estimator and checked for differences between both groups by the log-rank test. To evaluate differences in color, values were calculated according to the recommendation of the Commission Internationale de l'Eclairage using the following formula:[11]

$$\Delta E = \sqrt{(L1-L2)^2+(a1-a2)^2+(b1-b2)^2}$$

ΔE-values were calculated between the first measurement after the insertion and the following measuring times (six ΔE values per crown). In addition to the descriptive evaluation of the data, the differences between the CeMCs and CoMCs regarding defect rate, periodontal findings, and discolorations were also examined. P-values ≤0.05 were considered significant.

# RESULTS

## DESCRIPTIVE STATISTICS

The course of the study is shown in Figure 1. Nineteen patients, with an average age of 49 years, took part in the study (10 females and 9 males). The complete patient cohort was re-examined until the follow-up after 30 months. One patient dropped out of the clinical study at the 42-month follow-up. After 10 years, 15 patients were examined in follow-up tests. Four patients were unavailable when the follow-ups were arranged *(Table 2)*. The number of teeth which required crowns, which corresponded to the inclusion criteria of the study, consisted of 24 anterior teeth, 22 premolars, and 18 molars. A total of 64 crowns were placed, 31 CeMCs and 33 CoMCs.

Fifteen complications took place on the teeth that were investigated over the entire period. These consisted of eleven biological complications and four technical complications. The endodontically treated teeth had been kept in the study population in the absence of macroscopic effects on veneering. The distribution of the complications among the different materials is shown in Table 3.

Thus, the survival rate of CeMCs and CoMCs over the 10-year follow-up was 87.1% and 87.9%, respectively (log-rank test, p = 0.923) *(Figure 1)*.

## DEFECTS

The survival rates and the survival rate without mechanical defects or complications are shown in Figure 2 and 3. The first defect timepoints for CoMCs occurred significantly earlier compared to those of CeMCs. The most common type of defect in both materials was chipping. Most instances of chipping could be detected during the follow-up examinations after 30 months and 10 years *(Figure 2)*. The general survival rate after 10 years was 87.1% for CeMCs and 87.8% for CoMCs (log-rank test, p = 0.896) *(Figure 3)*. The survival rate without mechanical defects after 10 years was 83.9% for CeMCs and 51.5 for CoMCs (log-rank test, p = 0.009) *(Figure 4)*.



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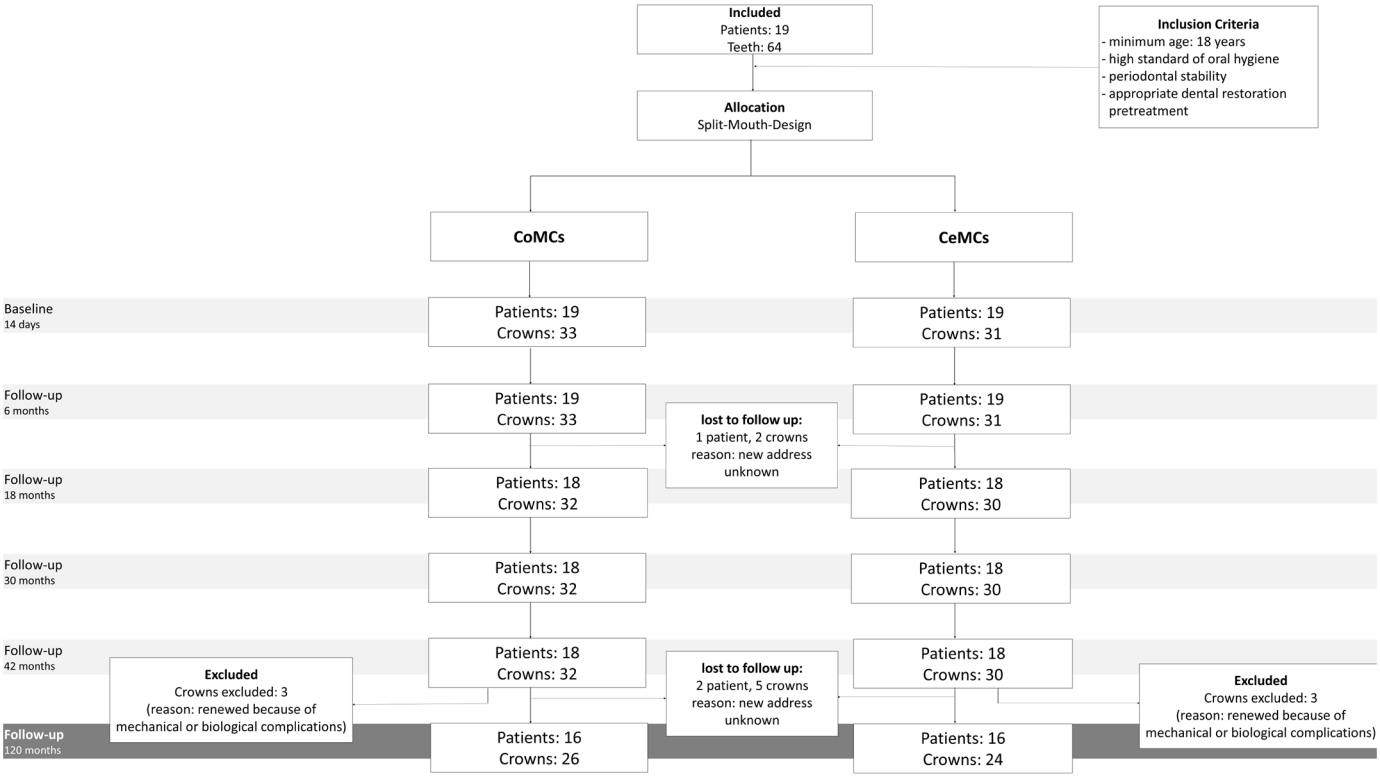


**Figure 1:** Consort Diagram

**Table 2.** Patient characteristics

| Patient characteristics | Study onset | | Follow-up after 10 years | |
|---|---|---|---|---|
| Number of patients | 19 | | 15 | |
| | Male | Female | Male | Female |
| | 9 (47.4%) | 10 (52.6%) | 6 (40%) | 9 (60%) |
| Average age | 49 years (21–70) | | 58 years (31–81) | |

**Table 3.** Types of dental interventions: Abbreviations: ceramic veneered metal crowns (CeMCs); composite veneered metal crowns (CoMCs)

| | | CeMC | CoMC |
|---|---|---|---|
| Dental interventions | None | 23 | 26 |
| | Trepanated teeth | 4 | 3 |
| | Renewed crowns | 2 | 2 |
| | Extracted teeth | 2 | 2 |

## SBI

The SBI values of the two groups differed depending on the time of the examination. However, in the 10-year follow-up, no significant differences were found in any group based on the time of insertion. The groups examined did not show significant differences in the SBI at any time (Kruskal–Wallis one-way analysis of variance, p>0.05)(*Figure 5*).



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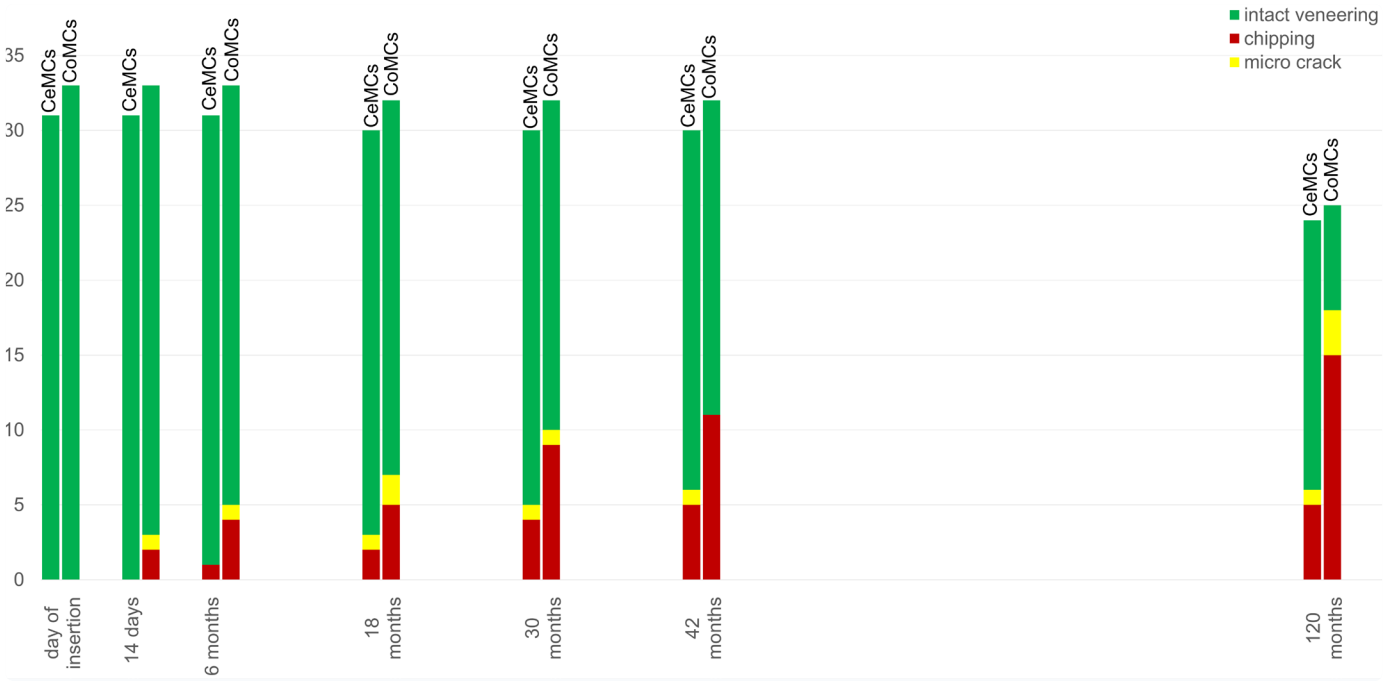


**Figure 2:** Temporal variations of defects for ceramic veneered metal crowns (CeMCs) and composite veneered metal crowns (CoMCs). Abbreviations: ceramic veneered metal crowns (CeMCs); composite veneered metal crowns (CoMCs)

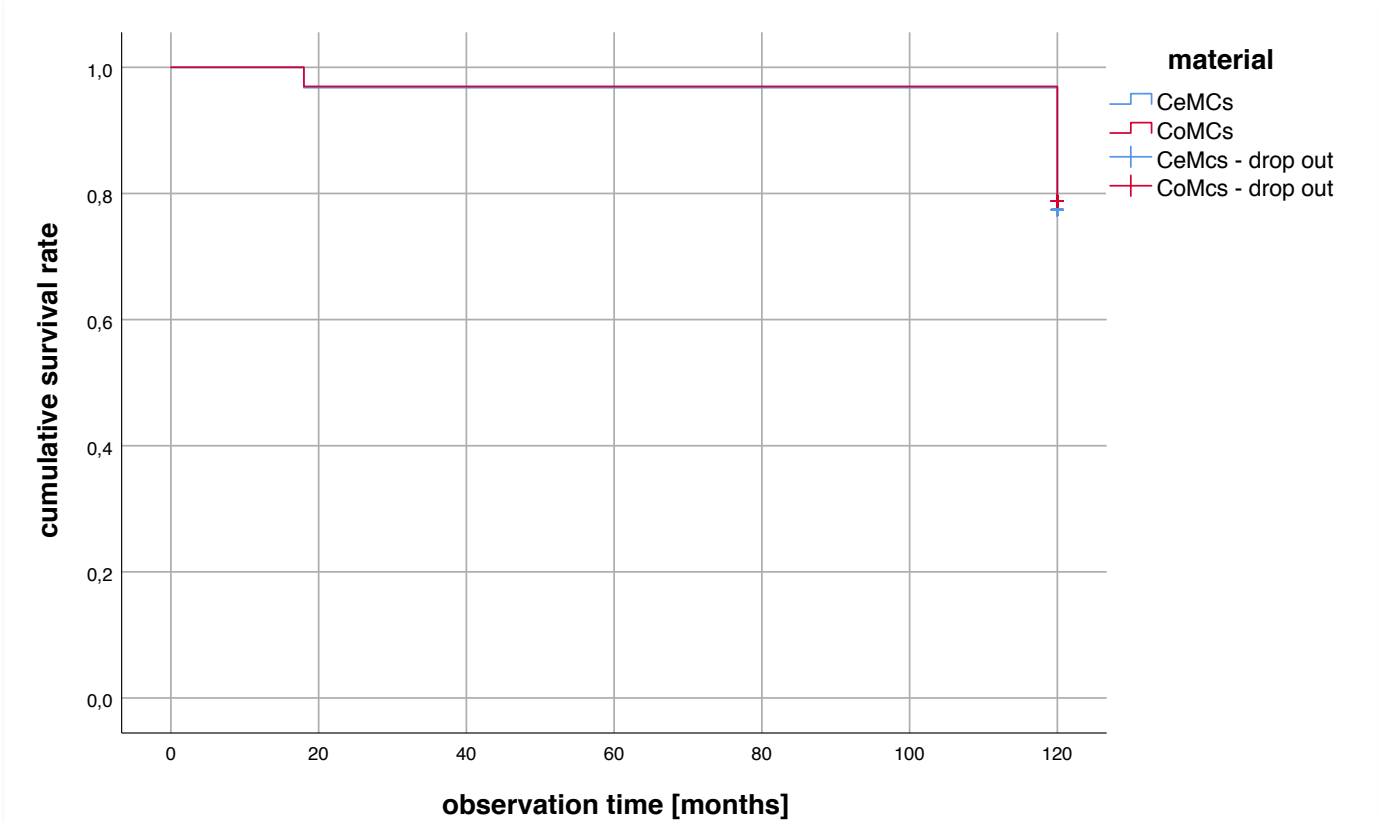


**Figure 3:** Crown-restoration-based Kaplan–Meier cumulative survival rate functions for the primary outcomes of loss of tooth or loss of crown. Abbreviations: ceramic veneered metal crowns (CeMCs); composite veneered metal crowns (CoMCs)

## PROBING DEPTH

The probing depths of teeth with CeMCs increased from 2.45 ± 0.62 mm to 3.63 ± 1.53 mm over the entire study period (p = 0.008, Pillai's trace), while the probing depths of teeth with CoMCs increased from 2.60 ± 0.61 mm to 3.52 ± 1.19 mm (p = 0.037, Pillai's trace). Additionally, the probing depths of the reference teeth increased from 2.78 ± 0.63 mm to 2.97 ± 0.97



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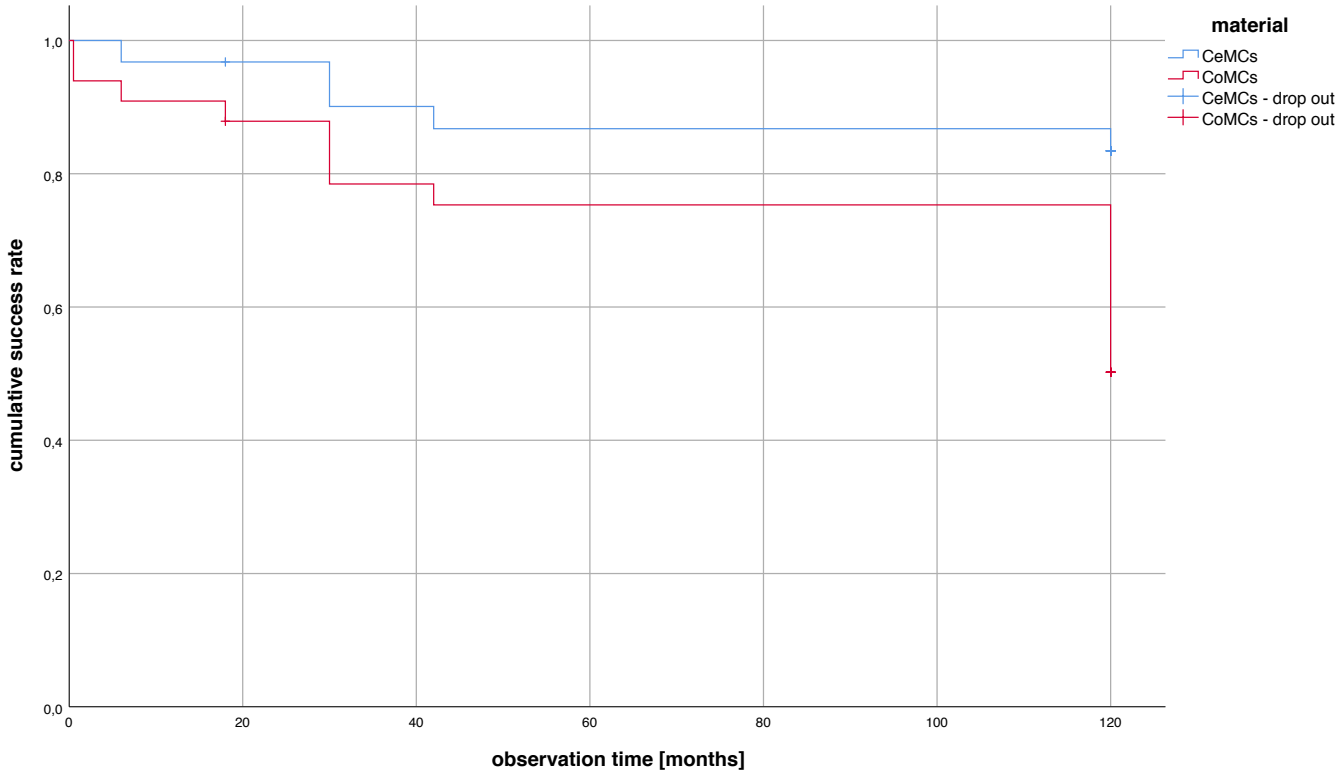


**Figure 4:** Crown-restoration-based Kaplan–Meier success rate functions for the primary outcomes of "metal ceramic defects". Abbreviations: ceramic veneered metal crowns (CeMCs); composite veneered metal crowns (CoMCs)

mm over the study period (p = 0.040, Pillai's trace). The groups did not show significant differences in pocket depths at any time during the investigations (p>0.05, ANOVA) *(Figure 6)*.

## PERIODONTAL RECESSIONS

The recessions of teeth with CeMCs increased from 0.37 ± 0.66 mm to 1.08 ± 1.44 mm over the entire study period (p = 0.143, Pillai's trace). The recessions of teeth with CoMCs increased from 0.23 ± 0.42 mm to 1.22 ± 1.44 mm (p = 0.091, Pillai's trace), while the recessions of the reference teeth increased from 0.69 ± 0.89 mm to 0.69 ± 1.00 mm (p = 0.779, Pillai's trace). The groups did not show significant differences in periodontal recessions at any time during the investigations (p>0.05, ANOVA) *(Figure 7)*.

## DISCOLORATIONS

The initial value of the color change (baseline measurement) was measured 14 days after the onset of the study for each participant. The ΔE value of CeMCs increased from 2.74 ± 2.09 (6 months compared to the baseline measurement) to 5.26 ± 4.68 (120 months vs. baseline, Friedman test, p = 0.153). The ΔE value of CoMCs increased from 2.66 ± 1.5 (6 months vs. baseline) to 7.23 ± 4.4 (120 months to baseline, Friedman test, p < 0.001). The mean ΔE values differed significantly after 30 months (ΔE = 1.18, Mann–Whitney U test, p = 0.033) and after 120 months (ΔE = 1.97 Mann–Whitney U test, p = 0.017) *(Figure 8)*.

# DISCUSSION

The null hypothesis that there would be no differences between the investigated CeMCs and CoMCs could not be confirmed.

## MECHANICAL DEFECTS

With regard to the mechanical changes, increased defect rates were observed in the case of CoMCs compared with CeMCs. To the best of our knowledge, to this date, there are no other published clinical studies that have evaluated the defect rates of CoMCs compared to CeMCs. The defect and survival rates of the CeMCs were compared with existing clinical studies on this topic. The present clinical study presents comparable results with those reported in similar, recently published clinical studies, e.g. a study by Reitemeier *et al.*,[12] Pjetrussen[12] and Sailor *et al.*[14]

In the current study, the 10-year survival of CeMCs was 87.1% and the survival rate without mechanical defects was 83.9%. Reitemeier *et al.* described a survival rate of the CeMCs of 88.8% over a period of 8 years and a survival rate of 77.3% over a 10-year period.[12] Pjetrussen *et al.* described a survival rate of the CeMCs of 88.8% over a period of 8 years and a survival rate of 77.3% over a 10-year period.[13] Sailor *et al.*, described a survival rate of the CeMCs of 95.7% over a period of 5 years and a survival rate without technical or biological complications of 77.3% over a 10-year period.[14]



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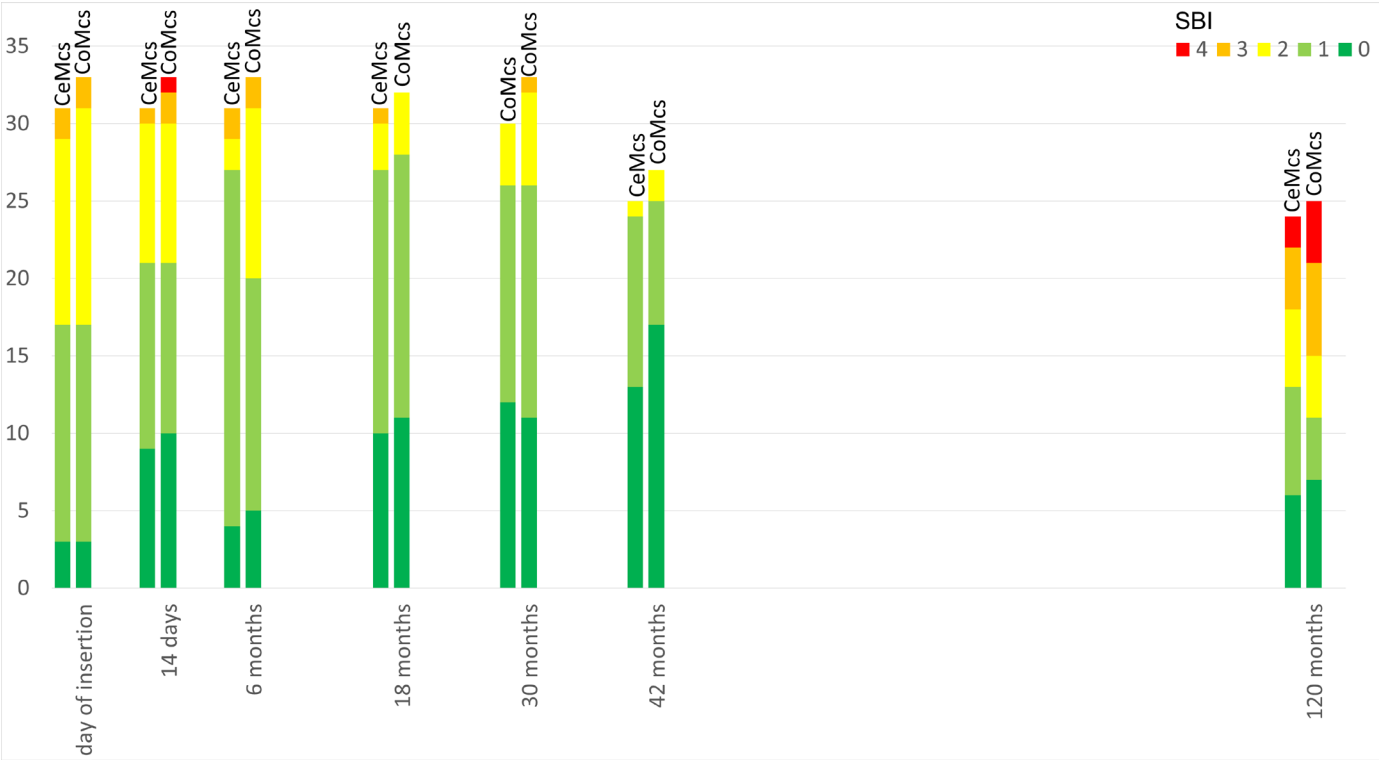


**Figure 5:** Quantification of SBI over time. Abbreviations: ceramic veneered metal crowns (CeMCs); composite veneered metal crowns (CoMCs)

*In vitro* investigations comparing the shear bond strength typically yielded higher bond strength values between metal and ceramic compared to those between metal and composite.[15] The bonds between composites and metals differ fundamentally from the ceramic–metal bonds. The adhesion of composites is achieved mechanically[1] with the use of undercuts, like the retention beads of the metal framework, and through chemical bonds produced with the aid of metal primers and tarnish treatments.[2] By contrast, the adhesion of the ceramic veneer to a metal is created by the shrinkage of the dental porcelain during cooling and the interfacial reaction between alloys and porcelains. This process is influenced positively by the increased wettability between the ceramic and metal.[16] Therefore, combined adhesion and cohesion fractures of the composite veneerings[17] are more frequent than pure cohesion fractures, and then also constitute the more typical defect type associated with the ceramic veneerings.[18] *In vivo*, the compound is reduced by aqueous environmental conditions, chewing forces,[17] and temperature differences during food intake.[19]

In addition, the differences in the coefficients of the thermal expansion of composites, metal frameworks, and the resulting material stresses lead to cracks.[3] The dipole–dipole character of the interconnections of the acrylic molecules is described as the reason for the reduced shear bond strength during storage in water. This bond strength is weakened by hydrolysis and finally dissolves.[17]

The brittle structure of the ceramic veneer results in the absence of elastic deformation.[8] As a result, loads that exceed a material-specific value lead to an immediate, spontaneous defect in the material. In an aqueous environment, subcritical chewing loads cause cracks which are initially invisible and which spread slowly.[19] This process is called "subcritical crack growth" and promotes material fatigue, water absorption, and predetermined breaking points. Rough surfaces and existing flaws contribute to the occurrence of these defects.[20] The repair process for the possible defects of both types of veneering materials can be executed using light-curing composites. Given that the composite used in this study is a material that is post-tempered by the application of heat and increased pressure, compromises must also be made in terms of the materials used for the repair.

The listed in situ crown defects at the 10-year follow-up examination did not indicate a new restoration and thus can be considered clinically acceptable. Most of the defects of the CoMCs occurred after 30 months. Ceramic veneering material remains the preferred material for the fabrication of fixed partial dentures. Composites are considered as veneering materials for long-term provisional and (conditional) removable prostheses. Furthermore, the average period of occurrence of the first defect is clinically acceptable in view of the low cost and simpler fabrication process.



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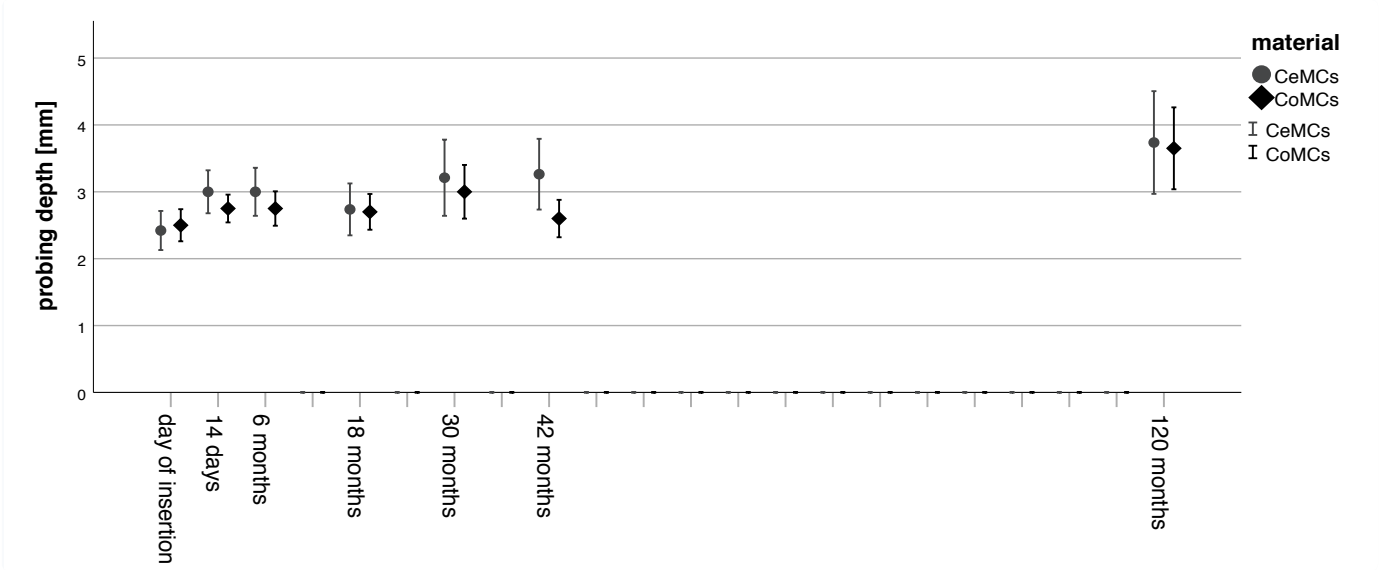


**Figure 6:** Mean values of probing depths over time. Abbreviations: ceramic veneered metal crowns (CeMCs); composite veneered metal crowns (CoMCs)

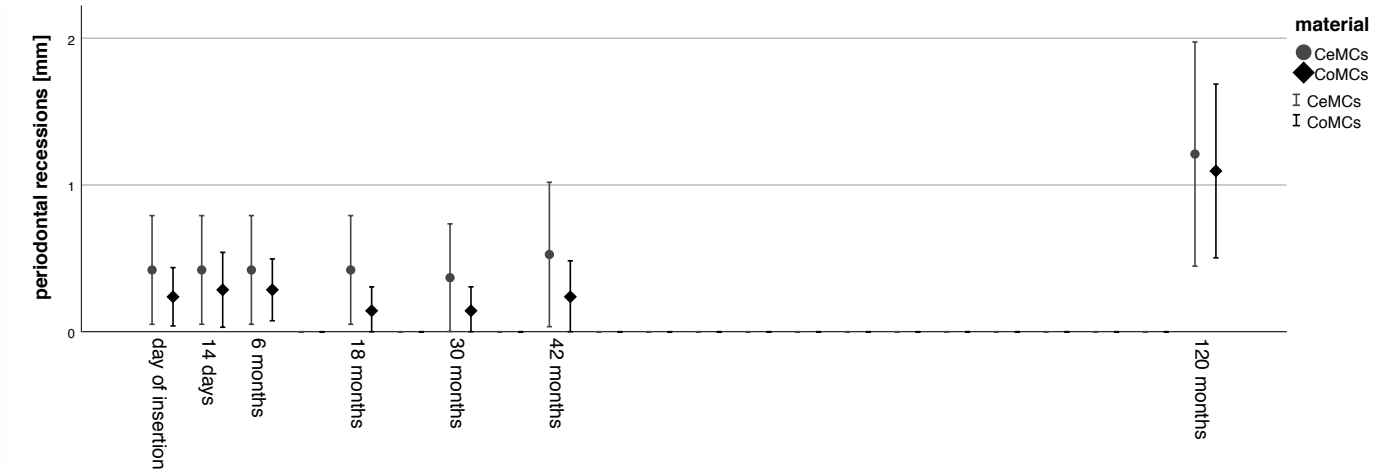


**Figure 7:** Mean values of periodontal recessions over time. Abbreviations: ceramic veneered metal crowns (CeMCs); composite veneered metal crowns (CoMCs)

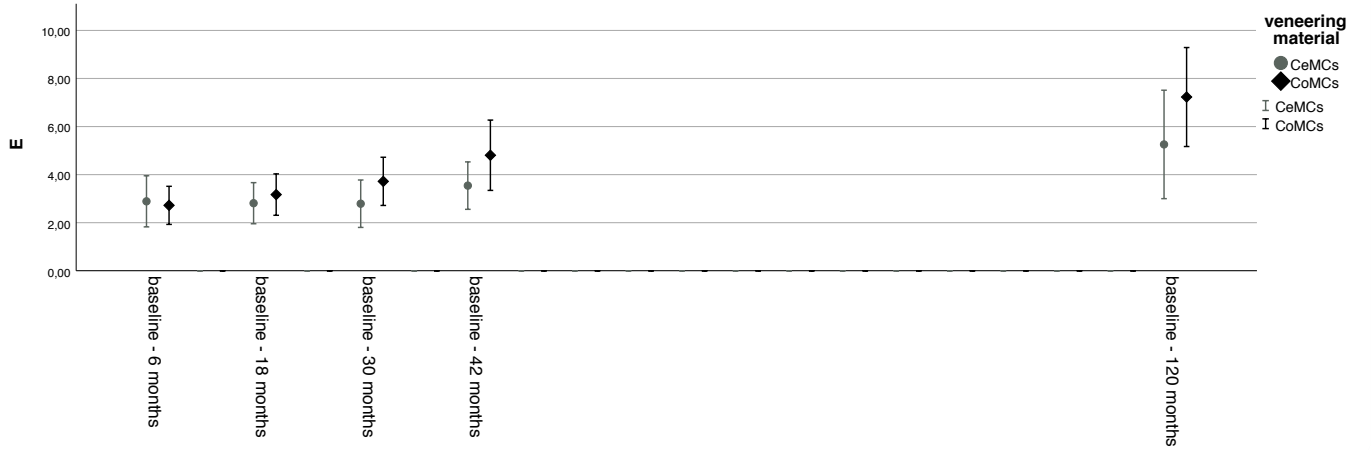


**Figure 8:** Mean values of ΔE over time. Abbreviations: ceramic veneered metal crowns (CeMCs); composite veneered metal crowns (CoMCs)



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## PERIODONTAL EXAMINATION

In general, clinical studies showed increased signs of periodontitis in crowned teeth compared to natural teeth.[21]An average increase of 0.2 mm in the probing depth was documented for the crowned teeth over a period of 5 years. This outcome corresponds to the results of other published clinical studies.[22] Periodontal recessions were in the range of other clinical studies and showed a similar increase.[22] The average SBI scores were within the range of comparable study populations.[23] The initial reduction in the inflammatory values of crowned teeth was also observed in other clinical studies.[24] One possible explanation for the initial reduction of inflammatory signs was the improvement of the oral hygiene observed in study patients who regularly participated in dental examinations.[25] This effect was most pronounced at the beginning of the study but had usually decreased by the final examination.

Various studies demonstrated a relationship between surface roughness and plaque deposition.[21] Increased plaque accumulation is a common cause of periodontal inflammatory signs, such as increased SBI, increased pocket depth, and periodontal recessions. In clinical studies, composites showed an increased plaque deposition compared to ceramic materials. This was mainly explained by the higher porosity of the surface.[26] In addition, the capacity of the composite to decompose was mentioned as an explanation for the development of increased surface roughness.[27] The results showed no significant differences between the materials.

It can be assumed that the surfaces of the veneerings exhibited increased surface roughness owing to external influences, which supported an increased plaque deposition. Furthermore, gingival recession may be accompanied by the exposure of the crown margin or by an increased roughness of the tooth neck, which may lead to increased plaque buildup. With the exception of the case of the reference teeth, there were increases in recession and probing depths on the examined teeth *(Figures 4 and 5*).

## DISCOLORATIONS

Over the observed period, the CoMCs exhibited a higher discoloration tendency compared to CeMCs. This result correlates with other published *in vitro* investigations,[5] but studies on the clinical comparison of the discoloration tendency of composite and ceramic veneerings are hardly available. The initial discoloration of the composite veneerings is a consequence of the changed material properties caused by the post-polymerization of the light-curing composites.[28] Remaining unconsumed initiators cause discoloration of the veneering material. *In vitro* studies showed that swelling caused by storage in water had a significant influence on the discoloration tendency of the composites.[28] Furthermore, the surface coating of the composite veneering is significant. The effect of food coloring ingredients on composite veneerings *in vitro* has also been analyzed and has been shown to be significant.[29]

The discoloration of the CeMCs that occurred at an early stage in this study was also described in other studies.[30] The color changes in the ceramics after short time periods were attributed to the fact that metal oxides added to the ceramic disintegrated due to ultraviolet (UV) irradiation and led to the formation of peroxide compounds that caused internal color changes.[30] A change in the surrounding environment also induced a tendency for color changes. Possible roughness which occurred after the modification process—regardless of how careful post-polishing was executed—and the generation of additional microcracks based on possible occlusion interferences of the veneering also influenced the discoloration of the CeMCs.[31] The simultaneous effects of the oral environment allowed corrosion in microcracks as well as accumulation of food coloring components, which could cause discoloration of the ceramic. Furthermore, food coloring constituents had an influence on the color changes of the CeMCs. Moreover, the effect of possible deposits of food components and plaque must be considered.

Even if the sensor is carefully positioned in the individually manufactured splint, deviations in the measurement location may occur. The individual layering of the veneerings resulted in a color difference that could be measured based on the small deviations of the measured location.[32] Based on the clinical study of Douglas *et al.*,[33] who investigated perceivable and clinically acceptable ΔE values, values of $\Delta E > 2.6$ were defined as being in the clinically perceptible range, while ΔE values above 5.6 were considered as clinically intolerable. Both materials were within the clinically acceptable range of values of $\Delta E < 5.6$ at the follow-up examination at 42 months. The color changes of the ceramic veneers within this period were comparable with the results of other similar clinical studies.[34] No clinical studies are available on the clinical discoloration of CoMCs.

Thus, after 10 years of wear, the mean color differences of the CeMCs were within the clinically acceptable range, whereas the color differences of the CoMCs reached a level that was considered clinically unacceptable. However, it can be assumed that neighboring teeth were also affected by extrinsic discoloration over time. Material-dependent differences in color changes were significant after 120 months.

## LIMITATIONS

The results of the study are limited by the relatively small sample size and also by the large time intervals between last and previous follow-up examinations, which also meant that there were different investigators between the last two follow-up examinations. Furthermore, patients of the investigated cohort were meanwhile receiving treatment in dental practices different from the study setting. In conclusion, the data collected were influenced by different treatment concepts with regard to periodontal treatments, adjacent tooth, and antagonist restorations. These factors include different crown wear due to different occlusion concepts.



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When comparing natural reference teeth, similar teeth from the opposite half of the jaw were used whenever possible. If this was not possible, a tooth of another type was chosen as a reference. In these cases, different oral hygiene capabilities cannot be excluded due to different accessibility. Patients with parafunctions were not included in the selection of study participants. However, this parafunctionally finding was not re-evaluated in the follow-up examinations. Particularly in view of the long study period, it is possible that parafunctions may have developed during the study period, which may have influenced the study results.

# CONCLUSIONS

Despite the improvements due to the use of composite materials, ceramic veneering remains the gold standard for metal crowns. After ten years of clinical use, discolorations as well as mechanical defects were considerably higher in CoMCs than in CeMCs. Thus, if long-lasting dentures are intended, ceramic veneering remains preferable.

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## CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

## ETHICAL APPROVAL

The study protocols were approved by the ethics committee of the medical faculty at the Martin Luther University Halle-Wittenberg (Ref. -Nr. 164/12.10.05/7) and were conducted in accordance with the Declaration of Helsinki and based on the conduct of medical research in accordance with ethical principles.

## INFORMED CONSENT

For this type of study, formal written consent was required.

## MANUFACTURERS' DETAILS

- Impregum/Permadyne, (3M Espe, Seefeld, Germany)
- SR Adoro (Ivoclar Vivadent, Schaan, Liechtenstein)
- IPS d.SIGN (Ivoclar Vivadent, Schaan, Liechtenstein)
- Academy Gold (Ivoclar Vivadent, Schaan, Liechtenstein)
- Fit Checker (GC, Leuven, Belgium)
- IPS InLine (Ivoclar Vivadent, Schaan, Liechtenstein)
- Polishing: kit 4312A for polishing composite, kit 4313B for polishing ceramics (Komet, Lemgo, Germany)
- RelyX Ultimate (3MEspe, Seefeld, Germany)
- spectrophotometer (Vita Easyshade Compact, VITA Zahnfabrik, Bad Säckingen, Germany)
- SPSS 22.0 (IBM, Armonk, New York, USA)

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