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Marginal Fit of Heat-pressed vs CAD/CAM Processed All-ceramic Onlays Using a Milling Unit Prototype

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Clinical Relevance

The marginal fit of all-ceramic restorations has an important influence on the clinical performance and lifetime of adhesively luted restorations. In proximal boxes, an average marginal gap of less than 100 µm is claimed. These clinical requirements are fulfilled by both processing procedures.

SUMMARY

The composite luting gap between ceramic and dental hard tissue can be termed an "Achilles heel." Therefore, one major goal of luting ceramics focuses on minimizing the inter-marginal gap area. This study evaluated the marginal accuracy of two all-ceramic systems. The null hypothesis was that there is no statistical difference between the marginal accuracy of the IPS Empress and Cerec 3D all-ceramic systems.

On 16 casts, representing different clinical situations, the left first mandibular molar was prepared to receive large onlays (MOD and replacement of the distobuccal and distal cusps). For each cavity, one laboratory heat-pressed (IPS Empress) and one chairside CAD/CAM restoration (Cerec 3D) were manufactured. A newly developed milling unit was used for CAM processing. The restorations were placed in their respective cavities and die replicas were taken and examined under SEM for quantitative gap measurement. The gap width was measured at 11 defined landmarks by two different examiners.

An overall gap width of 56 µm (± 31 µm) was measured for IPS Empress, compared to the significantly increased value of 70 µm (± 32 µm) for

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Cerec 3D. From a clinical viewpoint, the statistically significant difference between the two systems is not relevant, since both systems still exhibit a clinically acceptable gap width of less than 100 µm.

INTRODUCTION

All-ceramic restorations are recommended as an alternative to conventional metal-ceramic restorations.[1-5] An adhesive luting procedure allows for a minimally invasive cavity preparation, due to stabilization of the remaining tooth substance.[6] Excellent esthetics and superior biocompatibility are further advantages. However, the clinical procedure of adhesive luting is still a sensitive technique.[7-8] In general, the smaller the adhesive gap width, the easier the removal of composite material prior to polymerization.[7] This fact is especially decisive in the proximal region, because it keeps this region periodontally healthy and caries free. Marginal deficiencies accelerate plaque accumulation and susceptibility to recurrent caries.[9] Therefore, achieving a gap width below 100 µm is desirable.[7] Below this threshold, it is easily possible to remove excess composite without tearing composite out of the gap,[7] for example, by flossing. In addition, a reduced gap width is more resistant to wear. Due to an inherent polymerization shrinkage of luting composites, a small gap will help to minimize the risk of interfacial microcracking and microleakage by reducing polymerization stress.[10-11] An initial accurate fit of a restoration minimizes the clinical try-in procedure.

Although all-ceramic restorations are well documented and clinically proven,[3-5,12-13] the topics mentioned above are still of importance, and gap width accuracy is a major factor influencing clinical performance and lifetime of a restoration. The laboratory processed IPS Empress Esthetic (Ivoclar Vivadent, Schaan, Liechtenstein) and the chairside procedure with Cerec 3D (Sirona, Bensheim, Germany) are two well established all-ceramic systems.[14-22] In the literature, there is a lack of systematic comparisons of the marginal fit between the processing routines.

Therefore, this study compared the two all-ceramic systems with respect to their marginal accuracy. The null hypothesis is that there is no statistical difference between the marginal accuracy of the heat-pressed IPS Empress Esthetic system and the CAD/CAM Cerec 3D method.

METHODS AND MATERIALS

Sixteen upper and lower epoxy resin casts (AlphaDie Top, Schütz-Dental GmbH, Rosbach, Germany) of patients with complete dentition were mounted in a semi-adjustable articulator. On the lower left first molar, MOD cavities were prepared. Additionally, the distobuccal and distal cusps were removed. The pairs of upper and lower casts served as simulation models for the production of an IPS Empress Esthetic (LAB) and Cerec 3D (CHAIR) restoration. The group of 16 was randomly divided in two groups. For the first eight cavities, LAB onlays were produced and their accuracy documented. Then, using the identical cavity, CHAIR onlays were manufactured. For the second group, the sequence changed, starting with the CHAIR restorations.

The LAB technique was simulated by taking a double-mix impression (Panasil binetics putty soft, Panasil contact two-in-one, Kettenbach, Eschenburg, Germany) for the upper and lower jaw. In the dental lab, the impressions were transferred into casts of Fuji Rock (Fujirock EP Grey, GC Europe, Leuven, Belgium) and mounted into a semi-adjustable articulator (Artex-articulator, Amann Girrbach, Pforzheim, Germany). The restorations then were modeled in wax, sprued at the distobuccal cusp and invested (IPS Empress Esthetic Speed, Ivoclar-Vivadent) by a ceramist with eight years of experience with the IPS Empress technique. The molds and ceramic blanks were pre-heated using a temperature ramp of 5°C/minute and held for 30 minutes at 250°C (wax burn out) and 60 minutes at 850°C. Subsequently, the blanks were heat-pressed at 1075°C with 5bar pressure into the molds (furnace: IPS Empress EP 500, Ivoclar-Vivadent). If necessary, the fit of the divested restorations was controlled and adjusted with fine diamonds. After carefully cleaning, the restorations were stained and glazed.

The CHAIR restorations were prepared in a single phantom appointment according to the recommendations and guidelines of the University of Zurich[23] using Cerec 3D software, version V3.0. The operator was successfully trained in two Cerec 3D university curricula and exhibited practical experience to assess and define the optimum parameters of the milling unit by performing more than 200 restorations in preliminary tests. For each CHAIR restoration, a static bite registration was made of silicone material (Futar D Scan, Kettenbach, Eschenburg, Germany). Three single optical impressions of the cavity and the static registration were made. The single optical impressions of the cavity were computed into a virtual 3-D model on the computer screen. Due to the fact that the optical data of the bite registration could be superimposed onto the 3-D model, it was possible to consider cuspal contact point placement during the virtual design of the restoration. The CAD model was CAM manufactured using feldspathic porcelain blanks (Cerec-Blocs, Vita-Zahnfabrik, Bad Säckingen, Germany). The milling parameters were set to 40 µm for the spacer and 20 µm for the adhesive gap. For the milling process, the prototype of a new milling unit was used—the Cerec MCXL (serial #0018). The manufacturer stated that this machine was further developed with regard to precision and time expenditure of the conventional milling unit. The fit of the freshly milled restorations was checked, as well as the tightness of the proximal contacts. The outer surface of the restorations was pre-polished with dark blue Sof-Lex discs (3M ESPE, St Paul, MN, USA). The restorations were then glazed in a furnace (Vita Vacumat, Vita Zahnfabrik) at 950°C.

The try-in procedure on the simulation cast was identical for both the CHAIR and LAB restorations. The procedure started with checking and adjusting the proximal contacts. The fit of the restorations was checked using low viscosity silicone (Fit Checker Black, GC Corporation, Tokyo, Japan). The marginal fit was assessed by an operator wearing loupes (Keeler Loupe, Birmingham, UK) in order to imitate clinical standards. One major aim of this study was to document the accuracy of the gingivo-proximal line angle. Thus, the proximal contacts of the restorations were completely removed in order to receive appropriate and analyzable replicas. The cavities and restorations were cleaned carefully with ethanol, and placement of the onlay was controlled. Then, a moldable segmental impression tray (Miratray-Mini, Hager & Werken GmbH & Co KG, Duisburg, Germany) was placed onto the restoration. A ball-shaped plugger, inserted through a hole in the mini-tray, fixed the restoration into position. The low viscous silicone material was then injected with a syringe between the space of the mini-tray and the phantom cast. After a curing time of six minutes, the impressions were carefully removed. The replicas were produced using an epoxy resin material (AlphaDie Top, Schütz-Dental GmbH, Rosbach, Germany).

Measuring Procedure

The replicas were mounted onto specimen holders, sputter coated with gold and examined under SEM (Leitz ISI SR 50, Akashi, Tokyo, Japan) using 20 KV acceleration voltage and backscatter electron mode (BEI). The images were collected under 50-fold magnification and 0° tilting in order to prevent dimensional distortion. The gap sizes were measured at 11 landmarks, as shown in Figures 1 and 2. On each landmark, five measurements at a distance of 250 µm were taken centrally around the defined landmark. Two independent examiners were calibrated prior to the actual measurements. In a preliminary calibration routine, the examiners had to evaluate the replicas of seven onlays, representing 11 landmarks each. Due to the five single measurements at each landmark, each examiner measured 385 single values. The mean deviations from the results of both examiners were calculated. Since an inter-examiner accuracy of below 7 µm within a confidence interval of 95% was obtained, the measurement protocol was regarded as practicable. Then, examination of the 16 CHAIR and 16 LAB restorations began. The mean values of each landmark were calculated from the 10 single values of the two independent examiners. Descriptive analysis and pairwise comparisons between the CHAIR and LAB system were computed using the pairwise t-test at $p \leq 0.05$. The concordance of the measurement results of the two examiners was characterized by the Pearson correlation coefficient and by determining the confidence interval of the mean values that were calculated from the differences of the single measurement pairs by examiners 1 and 2.

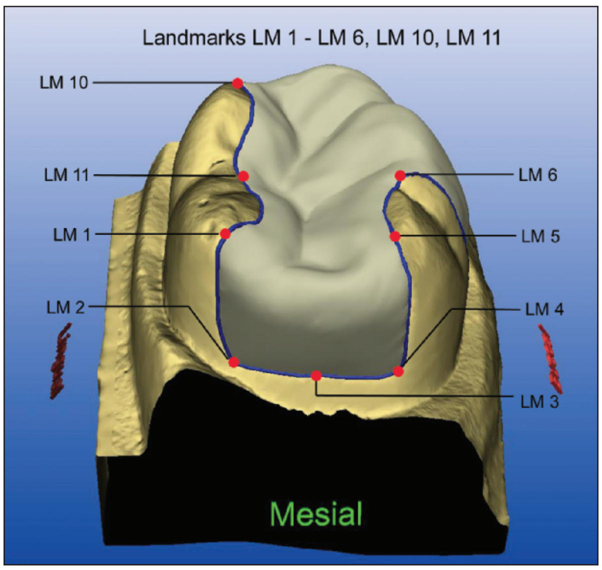

Figure 1. *Screenshot (mesial view) with marked locations (landmarks LM1-LM6, LM10, LM11) for marginal interfacial width measurement.*

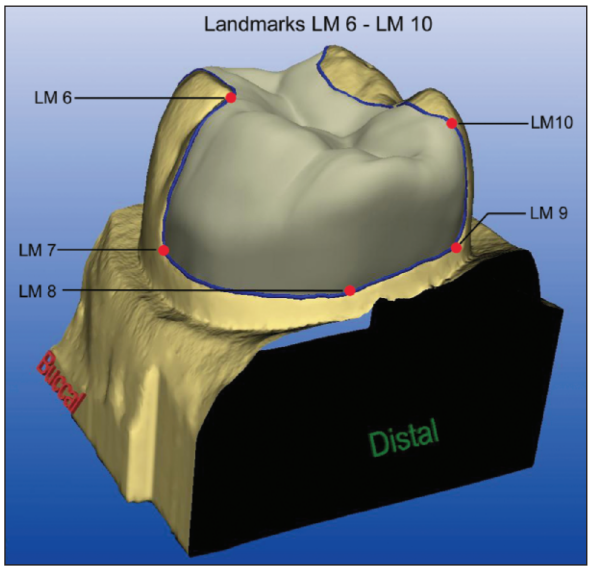

Figure 2. *Screenshot (distal view) with marked locations (landmarks LM6-LM10) for marginal interfacial width measurement.*

Table 1: *The means, medians, standard deviations (SD) and confidence interval for the means at 95% for the overall width and for each landmark for the two processing types CHAIR and LAB are displayed. Symmetric landmarks are merged.*

		(Chair)					(Lab)				
Landmark(s) (LM)	N	Confidence Interval (µm)		Median (µm)	SD (µm)	Mean (µm)	Mean (µm)	SD (µm)	Median (µm)	Confidence Interval (µm)	
		Lower	Upper							Upper	Lower
Overall	176	65	75	68	32	70 [a]	56 [a]	31	49	61	51
1 + 5	32	60	79	68	27	70 [b]	54 [b]	23	50	62	45
2 + 4	32	61	86	68	35	73	70	34	60	82	58
3	16	45	87	59	40	66	57	48	35	83	32
6	16	51	84	66	31	67	46	25	42	59	33
7	16	60	83	67	22	71	61	44	46	85	38
8	16	24	45	28	19	35	41	31	33	57	25
9	16	63	91	81	26	77	55	26	56	69	42
10	16	60	90	64	28	75 [c]	57 [c]	21	52	69	46
11	16	78	110	95	30	94 [d]	49 [d]	14	48	57	41

Superscript letters indicate statistically significant differences applying the pairwise t*-test at* $p \leq 0.05$.

RESULTS

Overall mean gap widths of 56 µm (± 31 µm) and 70 µm (± 32 µm) were revealed for LAB and CHAIR procedures, respectively. Due to the fact that the two values differed significantly at $p \leq 0.05$ (p-value=0.000), the null hypothesis that "there is no statistical difference between the marginal accuracy of the heat-pressed IPS Empress Esthetic system and the CAD/CAM Cerec 3D method" has to be rejected.

The Pearson correlation coefficient for the two examiners was calculated to be 0.85 for LAB and 0.82 for CHAIR. For both the LAB and CHAIR systems, the two examiners showed a mean deviation in their measurements that was below 9 µm (confidence interval 95%).

For further differentiation, the landmarks (LM) were analyzed individually and summarized in Table 1. LM2 and LM4 and LM1 and LM5 were merged together, due to their symmetric location.

The pairwise comparisons of the LAB vs CHAIR landmarks led to no statistically significant differences regarding LM2 and LM4, LM3 and LM6–LM9. LM1 and LM5, LM10 and LM11 exhibited statistically significant differences in terms of reduced gap widths for LAB compared to CHAIR. The margins of the CHAIR restorations were sometimes affected by chippings (Figure 3). The chipped areas exhibited a more uneven texture than the marginal defects of the LAB onlays (Figure 4).

Figures 3 and 4. *Exemplary scanning electron microscope (SEM) images at 50x magnification to demonstrate the characteristic chippings (red arrow). The images show the restorations for both technologies at LM1 and the same cavity.*

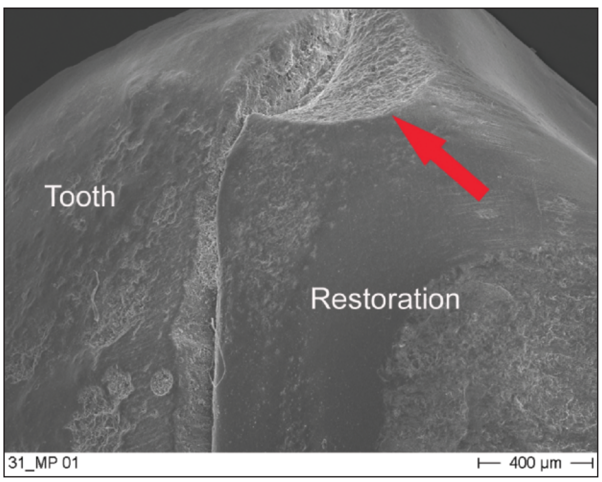

Figure 3. *Cerec 3D (CHAIR) restoration.*

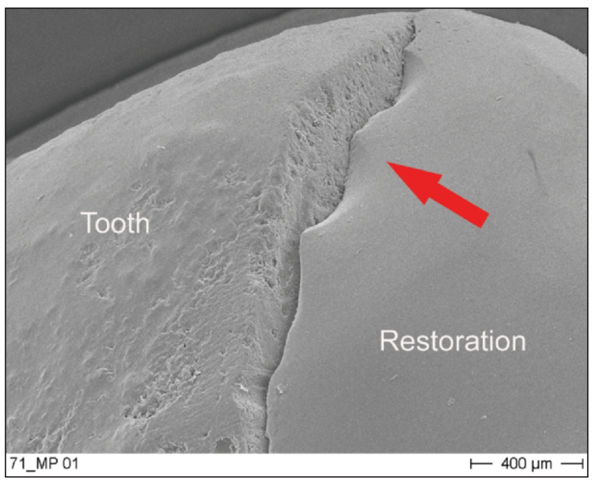

Figure 4. *Empress Esthetic (LAB) restoration.*

DISCUSSION

Values Under Investigation

Apart from the scientific outcome of this study exhibiting significantly different gap widths, the clinical standpoint certifies satisfying values for both systems. Marginal widths below 100 µm are clinically acceptable.[7] One major goal of the current study was to document the accuracy of the gingivo-proximal line angles represented by LM2, LM4, LM9 and LM3. Both systems did not show any significant differences, represented by pairwise comparisons of LM2 and LM4, LM9 and LM3. The results further showed the lowest mean gap widths for both systems at LM8. This area, which is identical to a shoulder preparation with an even and distinct geometry, is also described as an ideal geometry for a heat-pressed ceramic as for CAD/CAM systems.[24-25] This observation may lead to the conclusion that crown preparations with a shoulder as a finish line provide marginal conditions that may facilitate even reduced gap sizes. Ahbar and others and Tsitrou and others measured similar values.[24-25]

The highest single mean value under investigation was measured to be 94 µm at LM11 for CHAIR. This can be explained by the geometrical shape in this area, since the occlusal and internal surfaces have to be machined at an acute angle, which is confirmed by small chippings in those areas (Figure 3).

Comparison with Literature Values

With respect to the Cerec system and *in-vitro* investigations, studies that investigated the accuracy of Cerec 2 restorations can be found. Denissen and others measured full-coverage onlays on stone dies and found mean marginal gaps of 85 µm (± 40 µm) using the Cerec 2 device. The CAD/CAM systems Cicero and Procera, which were tested as well, revealed 74 µm (± 15 µm) and 68 µm (± 53 µm), respectively.[17] For MOD inlays with Cerec 2, Martin and Jedynakiewicz detected at the gingivo-approximal line angle on extracted premolars of 150 µm (± 52 µm) and 168 µm (± 72 µm) after adhesive luting, depending on whether they were located above or below the cemento-enamel junction.[16] These landmarks were located on comparable positions as LM2 and LM4, which revealed a mean of 73 µm (± 35 µm). However, comparisons between Cerec 2 and Cerec 3D systems have to be carefully assessed, since the milling process and the software platform have been totally changed. One major difference was that the Cerec 2 milling unit employed a milling disk and cylindrical bur; whereas, the milling unit MCXL was equipped with a one-step bur and one cylindrical pointed bur.

Addi and others investigated the interface gap size of IPS Empress inlays manufactured by dental technician students.[26] The mean values were approximately 2.5 times higher in comparison to the results of the current study. At "gingivo-proximal" measuring points, which are comparable to LM2 and LM4 ([LAB] 70 µm, [CHAIR] 73 µm), LM3 ([LAB] 57 µm, [CHAIR] 66 µm) and LM9 ([LAB] 55 µm, [CHAIR] 77 µm), the authors revealed 167 µm (± 30 µm). At the "proximal" location, a gap of 153 µm (± 40 µm) was found. These locations are comparable to LM1 and LM5 ([LAB] 54 µm, [CHAIR] 70 µm) and LM10 ([LAB] 57 µm, [CHAIR] 75 µm).[26]

Discussion of the Method

To simulate study conditions as realistically as possible, one major goal was to include all laboratory and clinical processing steps. For evaluating *in vitro* and *in vivo* marginal accuracy, the replica technique is a well-documented procedure.[14,17,27] There is no practical way to clinically document gaps of the proximal boxes. Dismounting impression material clinically is commonly followed by loss of interproximal area information. Therefore, the proximal contacts in this study were reduced to produce complete impressions and thus to display the proximal gap.

It was decided to work on one preparation with both systems without definite luting of the restorations, so that they could be statistically assessed as paired samples.

The preparation design ensured a safe reposition of the onlay restorations, so that it was possible to produce exact replicas. A comparable Pearson correlation coefficient for CHAIR and LAB, and the mean measurement deviation of below 9 µm between the two examiners, pointed out a highly reliable measurement procedure.

Edge Quality

The marginal edges of the restorations are stressed in a different way during the manufacturing processes, as shown in Figures 3 and 4. Especially during the milling process, the processing type CHAIR exhibited characteristic chipping edge fractures, whereas, the heat-pressed type LAB showed less prominent edge deficiencies. Chipping fractures are reported to substantially influence clinical lifetimes. One study evaluated clinical lifetimes with respect to specific reasons for ceramic fractures.[28] Small chipping fractures were found to be responsible for late clinical failures of ceramic restorations. The marginal chippings under investigation are, in fact, initially covered by the luting composite; however, after years of clinical service, they might be exposed by wear of the luting composite, induce slow crack growth and thus reduce clinical lifetimes.[7,28] However, from a clinical standpoint, this correlation can be relativized.

The above findings were found for IPS Empress restorations that were laboratory processed. After 12 years, 11 fractures were observed in 96 inlays and onlays. Reiss reported 89 failures in a group of 924 Cerec 1 and 2 inlays and onlays after 16 years of clinical service.[21] Approximately 35 restorations failed due to ceramic fracture. In relationship to the total amount of inserted restorations, the specific fracture rate of CAD/CAM machined ceramics is relatively low. These results are confirmed by Manhart and others, who, in their review, reported a slightly but not significant lower annual survival rate for laboratory processed inlays compared with CAD/CAM-manufactured ones.[29] In conclusion, there may be further parameters that influence catastrophic crack propagation, which start from marginal chippings, such as inherent inhomogenities and porosities.

CONCLUSIONS

The *in vitro* gap width measurements for both the IPS Empress system and the Cerec 3D method revealed satisfying mean results below 100 µm.

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