

A Measurement Protocol for the Marginal and Internal Fit of All-Ceramic Crowns

Keywords

Veneer
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ABSTRACT

Aims: To evaluate in vitro the influence of firing on marginal and internal fit of all-ceramic milled and pressed lithium-disilicate crowns. *Materials and methods:* One Standardized model with 1.6mm occlusal and 1.4mm axial reduction was used to fabricate 64 crowns. Using a factorial design, eight groups of lithium disilicate ceramics (n=8) using P=press, C=CAD/CAM, M=monolithic, O=coping, V=veneered, R=as produced: PMR, PMG, POR, PVG, CMR, CMG, COR, CVG. Crowns were produced and cemented on stone dies, then embedded in clear epoxy resin and sectioned into two plains. With a digital microscope, the distance between die and crowns was measured at the occlusal and axial walls. The horizontal/vertical fit at the finishing line of each section were measured as well. *Results:* For the marginal fit, the analysis shows that the influence of material and design was significant on horizontal and vertical margins, and the influence of finish was significant with horizontal but not vertical margins ($p=0.09$). For the internal fit, the analysis showed that the axial gap was significantly influenced by material and finish but not by design ($p=0.44$). *Conclusions:* With a few exceptions, horizontal and vertical marginal discrepancies were below 100 μm . Additional firing increased the discrepancies.

INTRODUCTION

With the increase in patients demand for esthetic restorations, all-ceramic restorations have been used successfully for restoring anterior esthetic zone as well as posterior teeth. Conventional metal-ceramic restorations provide acceptable appearance but they may cause a change of shade on the free gingival margin caused by the translucency of the gingival tissue.¹ The metal substructure causes a lack of translucency in the overall restoration due to the opacity of the material, thus resulting in a less than ideal appearance of the restoration.^{2,3} Many of the new all ceramic restorations have impressive physical and mechanical properties.⁴ Currently, two of the most popular ceramic restorative materials are lithium disilicate and zirconia, with lithium disilicate having higher translucency and lower mechanical strength than zirconia.^{5,6} Lithium disilicate has evolved since its introduction in 1998. IPS Empress II is a lithium disilicate ($2\text{SiO}_2\text{-Li}_2\text{O}$) glass ceramic that does not bear any resemblance to the earlier leucite glass ceramic. The material has average fracture strength of 350 MPa.⁷ In 2005, a new material family was introduced: IPS e.max. The improved press ceramic material consists of lithium disilicate glass ceramic, having the same chemical basis as IPS Empress II but with changes in the firing process and the framework design, it can be veneered with a new type of sintered fluoroapatite ceramic. As a result, improved physical properties and better translucency are reached. Using the same chemistry, various manufacturing processes can be used to produce restorations such as press technique (IPS e.max Press) or

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partially crystallized ceramic blocks for milling (IPS e.max CAD). The heat-pressing technique has been developed to overcome the inhomogeneity and porosity of manually layered and sintered restorations that occurs during fabrication, and it can be used to fabricate lithium-disilicate ceramic restorations. The heat pressing technique is based on the lost-wax principle. Pre-fabricated ceramic ingots of lithium-disilicate ceramic are heated and then pressed into the lost-wax form of the crown coping.⁸ The lithium disilicate blocks IPS e.max CAD can be milled by use of computer aided design and computer aided manufacturing (CAD/CAM) systems. CAD/CAM can fabricate monolithic crowns chairside or in the laboratory with subsequent staining and characterization.⁹ Some clinicians prefer to use full contour ceramic restorations to overcome factors that may cause inferior core-veneer bond strength. Based upon present fatigue findings the application of CAD/CAM lithium-disilicate ceramic in monolithic/full-anatomic configuration resulted in fatigue resistant crowns, as shown with mouth-motion cyclic loading whereas hand-layer veneered zirconia crowns revealed a high susceptibility to early veneer failures.¹⁰ Marginal and internal accuracy of fit is valued as one of the most important criteria for the clinical quality and success of all-ceramic crowns.¹¹ Increased marginal discrepancies expose the luting material to the oral environment, thus leading to cement dissolution and microleakage. The cement seal becomes weak, permits the percolation of bacteria, and can cause inflammation of the vital pulp. One *in-vivo* study has provided evidence that a large marginal discrepancy in a fixed restoration correlates with a higher plaque index and reduced periodontal conditions and caries.³ The internal gap is the measurement between the axial wall of the prepared tooth and the internal surface of the produced restoration, while the same measurement at the margin is called marginal gap.¹² Furthermore, an angular combination of marginal gap and extension error is an absolute marginal discrepancy, which specifically defines the linear distance from the surface finish line of the preparation to the margin of the restoration. It is considered the best alternative measurement since it is always the largest error at the margin and reflects the total crown misfit at that point, both vertically and horizontally.¹² An increase in cement thickness can lead to higher amounts of water absorption. Water absorption results in hydrolytic degradation of resin cements, thus reducing the elastic modulus and the mechanical properties.¹³ One study demonstrated that an excessively thick cement layer may cause residual stresses on the tensile surface as a result of the viscoelastic deformation of the cement material under cyclic loading.¹⁴ Other possible causes of microleakage include lack of adhesion between luting cement and tooth structure. A study indicates that there is no difference in the cement thickness (fit) of any type of restoration, and margin discrepancy can be up to 120 microns, because 80 microns were difficult to assess even with a sharp explorer.¹⁵

The aim of this *in vitro* study was to evaluate the marginal and internal fit at lithium disilicate IPS e. max restorations with:

- a. Two different fabrication methods (press vs. CAD)
- b. With two different construction procedures (Monolithic vs. Veneering), and
- c. To find if the glazing has any influence on the fit.

The first Null-Hypothesis, is that there is no influence on the marginal and internal fit between the type of fabrication method (e.max Press restorations and e.max CAD). The second Null-Hypothesis is that there is no difference between the different construction procedure (monolithic vs veneering) and the third Null-hypothesis is no influence on the fit after restorations are glazed.

MATERIALS AND METHODS

The experimental design of the study is depicted in Figure 1. Two materials were used for the fabrication of the crowns: IPS e.max Press (P) and IPS e.max CAD (C). 64 single crowns were evaluated, 32 were fabricated by the press technique and 32 with CAD/CAM. Of each material, each group was divided in two subgroups (design) of 16 crowns per group which includes monolithic (M) and core (O). Moreover, each subgroup was divided into second subgroup (finishing) that include glaze (G) and without glaze (R). Using a factorial design, the following groups were created: PMR, PMG, POR, PVG, CMR, CMG, COR, CVG. For every cell, there were 8 replications (n=8), which yields a total of 64 restorations.

A standardized master model of tooth (Universal #30, reorder #594148) with ideal reduction as recommended by the manufacturer was used to fabricate all the 64 crowns in the study. The recommended reduction was 1.6 mm occlusally, 1.4 mm axially, 6° taper and an axial reduction (chamfer) of 1mm. As a first step, using an alignment device the occlusal surface of the master model was attached with sticky wax to a metal plate. Then it was lowered in to a plastic mold filled with stone sitting on the bottom plate which was parallel to the top plate (Figure 2). Then, using the same alignment device, 64 custom made standardized impression trays were made, and 64 poly vinyl siloxane impressions (Virtual XD) were taken having an equal impression material thickness around the prepared tooth. The impressions were subsequently poured with Violet Stone. With this procedure identical position of every stone model relative to a standard reference plane were obtained. This configuration was used later to cement the produced crown to.

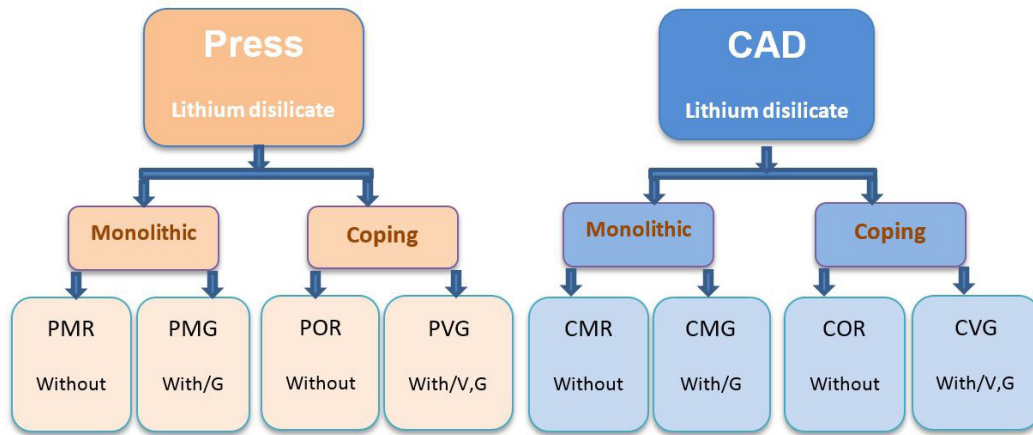


Figure 1: Experimental design

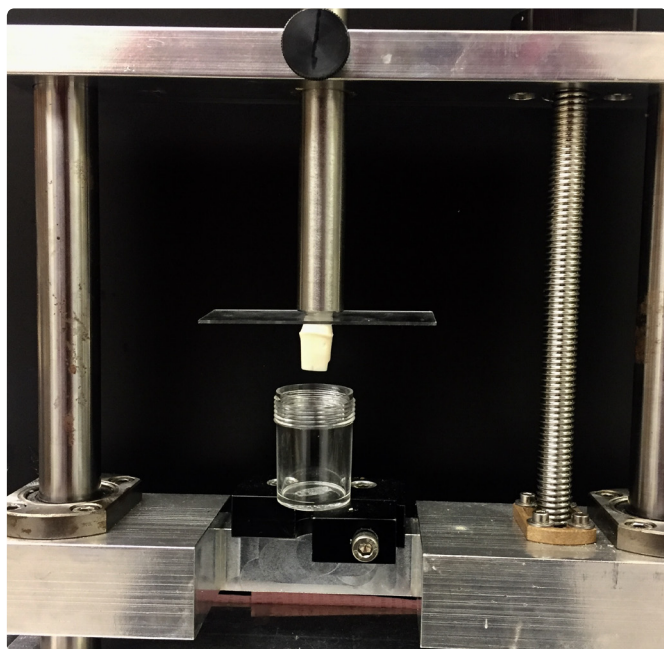


Figure 2: Master model standardization

IPS E.MAX PRESS FABRICATION

The e.max Press wax patterns for all crowns were obtained from the one master model, lubricated with 2 layers of die spacer. Wax build up for 16 e.max PV and 16 e.max PM crowns were made by using a wax injection device (Rio Mini Hand Wax Injector) using red wax (Jewelry injection wax). An individualized mold was created which fits to the injection hose of the wax injector and was repositioned on the master model, to standardize the wax thickness of the monolithic crowns (1.5 mm), and cores (1mm). A Programat EP 5000 was used to press the e.max ingots at 920°C using the appropriate program.

IPS E.MAX CAD FABRICATION

Prior to waxing the master model for e.max Press crowns, the prep was powdered using CEREC Optispray (Sirona), then scanned with a CEREC 3D Blue Cam (Sirona). The e.max CAD

crowns were fabricated with the CEREC System. Monolithic crowns were designed using the scanned wax pattern used for e.max Press restorations as a biogenic source (Figure 3). Using this construction 16 identical crowns were milled using the CEREC 3 Mill. The cement space was set as 40 µm. The copings were produced as described above, with the difference that the coping design was derived from the proposed crown by modifying the outer contour using the editing tools of the CEREC software.

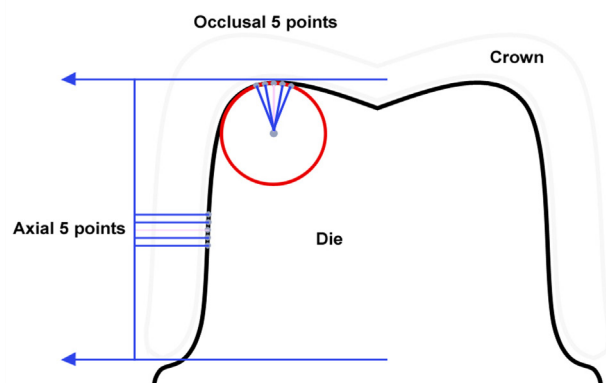


Figure 3: Internal point's selection

VENEERING AND GLAZING

The crowns and cores of groups PMG, PVG, CMG and CVG were veneered /glazed as follows: One layer of IPS e.max Ceram dentin was added up to 0.5 mm short of the margin over the cores to form and contour the shape of the crowns and fired. As the last step in the process, a thin layer of IPS e.max Glaze Powder and liquid was applied to the veneered crowns. The Monolithic groups were just glazed by a thin layer of e.max glaze powder and liquid.

CEMENTING OF THE CROWNS

All crowns were cemented to the corresponding die with modified resin cement (Multilink Automix) with added stain (Tetric color resin, brown) to the resin cement for better visibility during the

evaluation of sections. All crowns were cemented in the same insertion direction and at a seating load of 7.5 Kg, using a custom made device to load the crowns precisely in the axial direction. This simulates finger pressure to seat the crown in the patient mouth. After removing excess of the cement, light curing was performed with a radiant exposure of 10.79 J/cm² of the mesial, distal, buccal and oral side of the crowns using a polywave light curing unit (VALO cordless) to optimally cure the cement. The light curing was performed according to the manufacturer recommendations.

EMBEDDING AND SECTIONING OF THE CEMENTED CROWNS

The cemented crowns on the dies were embedded into clear epoxy resin (EpoFix Kit). Using marks on the dies and having a base parallel to the reference plane the cemented crowns were placed in a standardized position into cylindrical molds and poured with epoxy resin. These cylinders were fitted to the sectioning device (Isomet 1000, Buhler) using the reference marks visible through the clear epoxy. The resulting blocks were sectioned with a Isomet diamond saw at 150 rpm and 150 g load in two perpendicular directions from the occlusal surface buccal-lingual and mesial-distal in the midpoint of each side). This resulted into four sections to be evaluated for the internal and marginal fit of the crowns.

MEASURING THE GAPS

Five selected points of measurement by selected study zone in all sections were measured at a magnification of 300x to obtain the marginal and internal gap using a digital microscope (Keyence VHX-1000). Cement thickness was measured at the occlusal interface, the axial interface (Figure 4) and at the marginal area. For all measurements, the “path of draw” was used as a reference line. Since the dies were mounted in a standardized way, the base orientation could be transferred to the microscope before measuring.

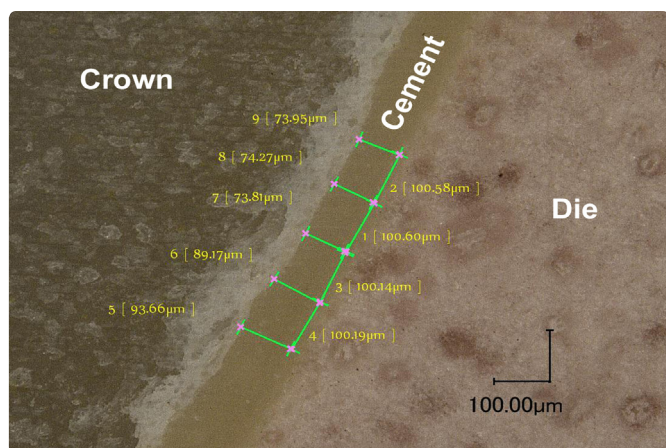


Figure 4: Axial point's selection

The internal cement layer thickness was determined at the location of the cusp tip and the geometric middle between the cusp tip and the margin area for the axial measurements. The cusp tip is defined as the tangential line drawn perpendicular

to the “path of draw” and touching the highest point of the die. To have almost perpendicular measurements the orientation of the subsequent two measurements to the right and left of the centerline 100 µm apart were drawn radial from the imaginary center of the curvature (Figure 3). For the axial wall two parallel lines above and below the centerline at a distance of 100 µm were measured. (Figure 4)

As described by Holmes *et al*, 1989, the marginal discrepancy (misfit) is divided into a vertical discrepancy and a horizontal discrepancy. The original measuring points were modified as follows in order to deal with the slightly rounded edges found on the ceramic and the die as well. The procedure is depicted in (Figure 5a). As a first step two lines, one of them the straight extension of the prepared finishing line (a) and the other straight extension of the outer surface of the die (b) are drawn. Then the angle bisector line is constructed (c). The point where the angle bisector line crosses the die is defined as measuring point (D). To determine an analog point on the restoration margin (C) two lines are drawn, one of them the straight extension of the inner surface of the restoration (d), and the other line as the straight extension of the outer surface of the restoration (e). The point where the angle bisector line (f) crosses the restoration is defined as measuring point (C).

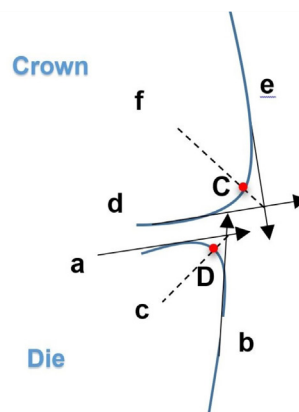


Figure 5a: Selection of the marginal points

The vertical misfit is defined as follows: The vertical distance between a horizontal line crossing (D) and a horizontal line crossing (C), see Figure 5b.

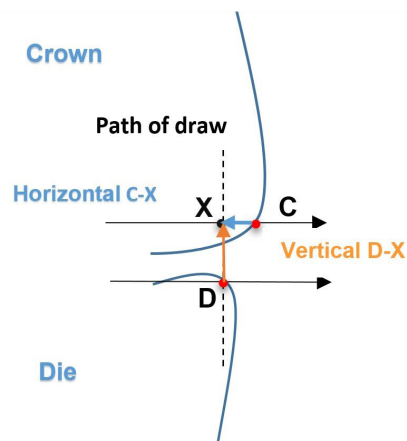


Figure 5b: Horizontal and vertical gaps definitions

The horizontal misfit is defined as the distance on the horizontal line between (C) and the crossing (X) of the path of draw going through (D), Figure 6a and b show the application of the protocol. There are two categories of horizontal misfit: 1) the crown is too big (overhang) and 2) the crown is smaller than the die (under extended). In summary, each crown sectioned in 2 planes yielded 4 quadrants. In each quadrant 5 occlusal, 5 axial, 1 horizontal and 1 vertical measurements were performed. Thus, per crown 20 occlusal, 20 axial, 4 horizontal and 4 vertical measurements were performed.

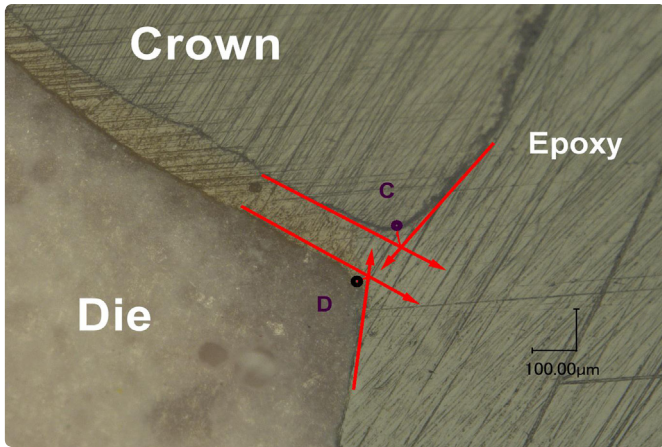


Figure 6a: Microscopic application of selected points

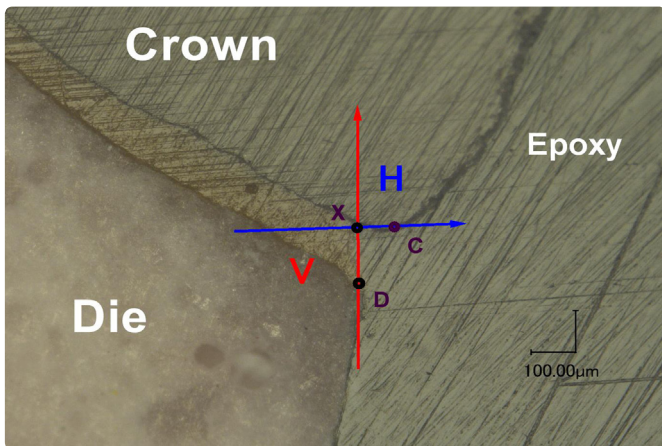


Figure 6b: Microscopic definition of horizontal (H) and vertical (V) gaps

Power analysis (SAS 9.4) of the mean values and standard deviation of a preliminary study with four monolithic crowns as manufactured from each material showed that eight crowns in each group of study would be sufficient to detect statistical difference at 5% level of significance and power at 80%. A three-way ANOVA and post-hoc Tukey test (SAS, 9.4) was performed to analyze the data. In case of interactions the analysis was broken down to 3 two ways ANOVA for every measuring location occlusal, axial, horizontal and vertical.

RESULTS

The mean values along with standard deviation of the gap measurements for each experimental group were calculated (Table 1). One-way ANOVA was used to determine statistical difference among the experimental groups for each location of measurement. Statistical difference ($p < 0.0001$) was found for all locations of measurement. Tukey's grouping is also included in the table.

For the marginal fit, 3-way ANOVA shows that the influence of fabrication and construction procedure are significant on horizontal and vertical margin, and the influence of glazing was significant with horizontal but not vertical margin ($p = 0.09$). The overall means of vertical and horizontal margin were $154 \mu\text{m}$ and $97 \mu\text{m}$ for Press, and $56 \mu\text{m}$ and $70 \mu\text{m}$ for CAD. Glazing yielded a better horizontal marginal fit ($71 \mu\text{m}$) than those of non-glazed crowns ($95 \mu\text{m}$). Construction procedure had significant but opposite effect on the mean vertical and horizontal margin: $112 \mu\text{m}$ and $74 \mu\text{m}$ for monolithic, and $98 \mu\text{m}$ and $92 \mu\text{m}$ for coping. For the internal fit, 3-way ANOVA showed that the axial cement thickness is significantly influenced by fabrication and glazing but not by construction procedure ($p = 0.44$), while the occlusal cement thickness was significantly influenced by the construction procedure not by fabrication ($p = 0.29$) or glazing ($p = 0.34$).

Because of significant difference between Press and CAD for most gap measurements made, 2-way ANOVA was run for each material to investigate the influence of construction and

Table 1. The values of mean and SD of the gap measurements in μm for each experimental group.

Gap location	e.max Press				e.max CAD			
	Monolithic		Coping		Monolithic		Coping	
	PMR	PMG	PCR	PVG	CMR	CMG	CCR	CVG
Horizontal	104±57 ^{AB}	70±48 ^{CD}	121±35 ^A	89±25 ^{BC}	67±23 ^{CD}	54±27 ^D	86±22 ^{BC}	71±16 ^{CD}
Vertical	177±45 ^A	161±37 ^{AB}	132±31 ^C	144±47 ^{BC}	57±22 ^D	49±23 ^D	66±22 ^D	50±19 ^D
Axial	83±14 ^C	69±16 ^D	87±19 ^{BC}	89±23 ^{BC}	110±21 ^A	95±21 ^{BC}	97±15 ^{AB}	91±13 ^{BC}
Occlusal	93±13 ^{BC}	85±14 ^C	102±20 ^{AB}	112±28 ^A	105±19 ^{AB}	101±18 ^{AB}	101±17 ^{AB}	95±14 ^{BC}

*The same letter in superscript of the value indicates no statistically significant difference of the means in the same row

glazing on the measurement. The p-values as determined by 2-way ANOVA are summarized in Table 2. The effect of glazing is significant on three measurements for CAD but only one measurement for Press. On the other hand, the influence of construction procedure is significant

The horizontal gaps have more clinical significance than vertical gaps and the internal gaps as well so we created an index to make the results more clinically relevant. We were weighing the horizontal gap x4, the vertical x2, and both axial and occlusal gaps x1, to see overall effect of material, design, and finishing on the marginal discrepancy. The Table 3, for the clinical significance index showed, overall e.max CAD had a lower index than e.max Press groups. Within e.max CAD groups the monolithic glazed has the lowest index followed by the coping with veneered /glazed group. All groups for both materials showed marginal gaps within acceptable limits below 120µm according to Holmes et.al 1989. The first hypothesis was rejected, while the second had to be accepted for e.max Press and rejected for e.max CAD.

DISCUSSION

In this study, there was a need to very precisely define the gaps or the misfit between the crowns and the underlying prepared teeth. Holmes *et al.*,¹¹ were the first to establish clear definitions for the points used to measure internal gaps and marginal discrepancies for porcelain fused to metal (PFM) crowns. They mentioned that there were horizontal and vertical marginal discrepancies. However, dealing with PFM crowns the margins consisted of metal with very sharp edges in very sharp crown preparations. Therefore, they used these landmarks to define the measuring points. In a pilot study, which was run previously to the present study, it was found with full ceramic crowns that there were no sharp features neither on the crowns nor on the crown preparations and therefore it was very difficult to find the landmarks on a microscopic level. The outcome of the measurements was unsatisfactory because of a high SD. It was decided to use tangents and bisecting angle lines in order to come up with well defined, precise and reproducible measuring points see figures 3-5, which yielded a low SD for the marginal gaps. For the internal gaps,

Table 2. P-values of 2-way ANOVA on the effect of design procedure and glazing

Gap location	e.max Press			e.max CAD		
	Design	Glazing	Design*Glazing	Design	Glazing	Design*Glazing
Horizontal	0.0202	0.0001	0.9246	0.0001	0.0007	0.8201
Vertical	0.0001	0.7922	0.0505	0.1831	0.0021	0.2756
Axial	0.0004	0.0597	0.0186	0.0085	0.0011	0.1843
Occlusal	0.0001	0.7936	0.0107	0.0814	0.0789	0.6222

Table 3. Clinical significance index, the smaller number the better. H is the smallest index number.

Gap location	e.max Press				e.max CAD			
	Monolithic		Coping		Monolithic		Coping	
	PMR	PMG	POR	PVG	CMR	CMG	COR	CVG
Horizontal x4	416	280	484	356	268	216	344	284
Vertical x2	354	322	462	288	114	98	132	100
Axial x1	83	69	87	89	110	95	97	91
Occlusal x1	93	85	102	112	105	101	101	95
Accumulated Index	946	756	1135	845	597	510	674	570
Score within materials	B	D	A	C	B	D	A	C
All over score	B	D	A	C	F	H	E	G

Holmes *et al.*,¹¹ definitions for occlusal and axial gaps were followed with the modification of defining precisely the location and using multiple measuring points. Lithium disilicate ceramic was used as a material, because it offered the opportunity to compare two different manufacturing techniques with almost the identical material and identical requirements for the crown preparation (shape, thickness etc.). The limitation of this study was the number of area and measurement points. To have standardized internal measurements, 5 points were selected at the center of each area (axial and occlusal), sums up to 20 points per crown for internal gaps. Other limitation is selecting only one measuring point for (horizontal and vertical) per quadrant, sum of 4 points per crown per category was done. However, the horizontal and vertical points were precisely selected according to the described method, which gives more value to these measuring points. The total measuring points was 384 per group.

Sectioning in to 4 blocks yield 8 surfaces that could be used for measurements. However, a point 0.5 mm thick diamond blade was used yielding identical measurements on both sides, as determined in the pilot study. Therefore, it was decided to measure only in one side of each cut.

A three-way ANOVA showed significant differences ($p < 0.0001$). Both systems showed a variation in marginal and internal gap values due to differences in their procedures, materials and equipment during crown construction; therefore, the standardized fabrication technique could not be obtained. However, only one master model was used to make all crowns. The explanation for the significant difference among them, could be the fact that e.max Press crowns were fabricated through a combination of the lost-wax and heat-pressed techniques, and may have undergone dimensional changes caused using a die spacer before waxing, the shrinkage occurring during solidification of the wax, and the dimensional changes occurring in the investment process. Finally, the dimensional changes in glass-ceramic ingot when plasticized and pressed into an investment mold caused by the shrinkage after casting of the ingot could be related to the high fusing temperature which will cause greater fit discrepancy, and the expansion of the investment may be inadequate to compensate for the casting shrinkage and in turn obtaining a good fit.¹⁶ The other cause of marginal gap on the e.max Press group could be attributed to different degree of surface roughness produced in the investment material. Surface roughness will increase when using high mold temperatures.¹⁷

In the CAD-CAM world, the following process parameters may have influenced the precision of the produced crowns: inaccuracies during the scanning process, operator errors during the design phase and setting of the desired cement gap. Furthermore, during the translation of the design file into a STL-file for the milling process may occur and finally wear of the milling tools may add to the imprecision. The following may have lead the e.max CAD crowns to more precise fit: First we used one scan only and used the same design to produce all crowns. Second, despite the calibration steps that are integrated into the systems, the milling tools were changed frequently, according to manufacturer's instructions. The gaps

reported for the CAD/CAM crowns/copings as produced can mainly be allocated to the preset cementing space. Overall, the CAD/CAM processes can be controlled better being well defined and the possible occurrences for deviations are less.

Due to the specific way to define the measurement points for the marginal gaps and thus the precision of the fit it's hard to compare our results with previous studies.

In the present study, the results revealed that the veneering and glazing/firing had a significant effect on the e.max Press crowns, more with horizontal than vertical gaps. E.max Press crowns, which were veneered/glazed showed smaller gaps than the ones that were investigated just as produced. This slight shrinkage over all improved the margin quality of the e.max Press crowns, which was then not different from the margin quality of the e.max CAD crowns. This effect was not observed with the e.max CAD crowns. This different behavior may be explained by the slightly different crystallinity of the e.max Press and e.max CAD material.²² The additional firing had the same effect on the coping groups as on the monolithic groups. Overall, horizontal marginal gaps were smaller with monolithic groups and more accurate in the monolithic groups after glazing firing.

In the results, the index was used to weighting the harmful effect of any of these discrepancies and making the data clear to clinicians. The weighting was based on clinical experience. From clinical view, slight vertical discrepancy will result in thicker cement layer in the margin which is more difficult to handle (x2). However, horizontal discrepancy provides overhangs creating a plaque accumulation zone, which is considered harmful regarding to the potential to induce gingivitis, periodontitis and recurrent caries.²² Therefore, the highest factor(x4) was assigned to this condition. Intra oral gaps are of less significance since they determine the cement layer thickness. Due to determined internal gap size (die spacer or cement thickness in CAD/CAM) we didn't find "negative gaps" e.g. direct contact with the die. Therefore, we assigned those factor (x1). Validation is only possible with a clinical study, which was not the scope of the present paper.

The results of this study agree with the results of another study,⁶ that showed that porcelain firing significantly altered the marginal fit of their crowns. The distortion that occurred might be due to non-uniform porcelain mass and those crowns exhibited non-significant differences during the glaze firing. A study,¹⁵ found that the porcelain veneering had a statistically significant influence on the marginal fit of two milling systems, which is contradicting the results of the present study. However, the increase in the marginal gap in veneered copings after the body porcelain firing cycles may also be a result of porcelain contamination on the inner surfaces of copings, and reduction in the resilience of the core material and rigidity of the porcelain.¹⁸ The difference in coefficient of thermal expansion (CTE) of the veneering ceramic and the core material leads to compression of the veneering ceramic during cooling to room temperature, which leads to enhancement in bond strength between the two materials. This compression might affect the marginal fit, so the marginal fit changes in the veneering stages of the firing cycle could be attributed to (CTE) incompatibility of the veneering ceramic used and the core material,

which lead to stress effect on the marginal fit.¹⁹ Another explanation of the difference in marginal gap may be explained by the fact that during the porcelain veneering procedure, particles of porcelain melt and gather to fill up voids and the resulting contraction of the porcelain mass causes a compressive force on the coping.²⁰ The deformation of the coping under the stress of contracting porcelain is spread around the whole circumference of the margin. Therefore, the literature has suggested certain causes that may be responsible for the distortion such as: porcelain contraction, design and thickness of the core substructure and inadequate support of the core framework during firing.²¹

CONCLUSIONS

1. The Press crowns in general showed slightly larger gaps than the other groups.
2. The glazed monolithic CAD crowns showed the smallest gaps followed by veneered and glazed CAD crowns.
3. According to the clinical significance index both materials behaved the same, which means the monolithic glazed come has the least index number then veneered and glazed, monolithic as produced, and coping veneered respectively.

With a few exceptions, horizontal and vertical marginal discrepancies were below 120µm. Additional firing increased the marginal discrepancies. The e.max CAD crowns showed smaller gaps in the vertical and horizontal margin when compared to the e.max Press. similar or little more in axial and occlusal gaps.

MANUFACTURER'S DETAILS

- IPS e.max Press and IPS e.max CAD (Ivoclar Vivadent, Schaan, Lichtenstein)
- (Violet Stone type 4 Silky-Rock, Sterling, USA)
- (Virtual XD Ivoclar Vivadent)
- (Rio Grande, Rio Mini Hand Wax Injector) using red wax (Jewelry injection wax, Westcast USA)
- (Isomet 1000, Buehler Lake)
- (IPS PressVEST Speed, Ivoclar Vivadent)
- (Multilink Automix resin cement Ivoclar Vivadent)
- (Tetric color resin, brown, Ivoclar Vivadent)
- (VALO cordless, Ultradent, South Jordan, Utah)
- (EpoFix Kit, Struers Denmark)
- (Keyence VHX-1000, Japan).

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