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ORIGINAL ARTICLE

Measurement of cement thickness under lithium disilicate crowns using an impression material technique

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Abstract According to the literature, marginal gaps below 120 μm are recommended for conventionally cemented crown restorations. Therefore, the null hypothesis tested was as follows: the upper bound of the 95% confidence interval of the marginal accuracy of chair-side generated lithium disilicate crowns lies below 120 μm. Prior to definite insertion, the accuracy of 20 lithium disilicate crowns (e.max CAD LT) was evaluated by a replica technique. A light-body silicone was used to document the gap between crown and abutment. The thickness of the light-body silicone layer was examined under microscope (MM40, Nikon Corp., Tokyo, Japan; magnification, ×50) at four different landmarks (LM): LM1 = marginal discrepancy, LM2 = mid-axial discrepancy of the inner crown surface, LM3 = axio-occlusal discrepancy, and LM4 = mid-occlusal discrepancy. At LM1, the mean marginal discrepancy revealed 100 μm (SD, ±61 μm); the median was 81 μm. The lower bound of the 95% confidence interval was 90 μm, and the upper bound was 110 μm. The means of internal gaps at LM2, LM3, and LM4 showed 148 μm (SD, ±61 μm), 227 μm (SD, ±83 μm), and 284 μm (SD, ±95 μm), respectively. The lower bounds of the 95% confidence interval revealed values between 137 μm (LM2) and 269 μm (LM4). The upper bounds were between 158 μm (LM2) and 300 μm (LM4). The null hypothesis was not rejected. Within the limits of the study, the chair-side generated lithium disilicate crowns exhibited a sufficient clinical accuracy.

Keywords Dental materials · Ceramics · Clinical trial · Accuracy · Marginal gap · Lithium disilicate · Crown · Chair-side

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Introduction

The CAD/CAM (computer-assisted design/computer-assisted manufacturing) material IPS e.max CAD (Ivoclar Vivadent, Schaan, Liechtenstein) consists of a lithium disilicate ceramic. IPS e.max CAD is indicated for full contour anterior and posterior crowns and can be used for chair-side applications, in order to provide a permanent restoration for a patient in one single appointment.

The machinable blocks consist of a metasilicate phase and show a bluish color. After milling the restoration from the blank, the metasilicate phase is transferred to the final lithium disilicate structure, obtained by a crystallization firing at 840°C for 25 min. After sintering, a flexural strength of 360 MPa (±60 MPa) and a fracture toughness between 2 and 2.5 MPa*$m^{0.5}$ was measured [1]. Therefore, according to the manufacturers' instructions, IPS e.max CAD crowns can be either adhesively luted or convention-

ally cemented using zinc phosphate or glass-ionomer cement.

The marginal and internal fit of all-ceramic crowns is still of key importance for both conventionally cemented and adhesively luted restorations [2–4]. However, the marginal fit is one of the crucial criteria for the decision of the clinician, whether a restoration could be inserted or not.

Regardless of cement type, the crown margin width is still one of key importance limiting the durability of a restoration. Marginal gaps between 100 and 120 μm are deemed as clinically acceptable [5, 6] to avoid potential problems of wear or dissolution that might contribute to cement loss [7]. Margins up to 160 μm might be tolerable [6]. Besides the loss of pulp vitality of crowned teeth, the second most biological complication is caries [8]. Crown margins are prone to microleakage [9], and wide gaps may lead to secondary caries as clinical observations show [2, 3].

A good marginal accuracy tends to reduce recurrent caries and the risk of a restoration-related periodontal inflammation [10, 11]. The internal fit is of interest, too. The mid-axial wall discrepancy can be used as an indicator whether a crown is too narrow; the axio-occlusal and the mid-occlusal gap widths could show whether the crown is seated solidly; for example, if the occlusal discrepancy would exceed the spacer value that was set for the milling process, then this would be an indicator for an inaccurate milling process or the incidence of some primary contacts. While some clinical data evaluating the accuracy of crown restorations were published (Table 1), no clinical data of the fit of chair-side generated lithium disilicate ceramic crowns are available. Therefore, the null hypothesis tested was as follows: the upper bound of the 95% confidence interval of the marginal accuracy regarding chair-side generated lithium disilicate crowns lies below 120 μm.

Materials and methods

Thirty IPS e.max CAD LT (low translucency) lithium disilicate posterior crowns were inserted in 26 patients who showed the indication for a posterior crown restoration and agreed to take part in a clinical prospective study. The entire study was approved by the ethic committee of the University of Leipzig (application no. 103-2006). The restorations were manufactured chair-side by using the Cerec 3D system (Sirona, Bensheim, Germany, software version 2.9). The preparations were characterized by a marginal shoulder showing a width of at least 1 mm, an axial reduction of about 1.5 mm, and occlusal reductions in the area of cusps and the fissure line of 2.0 and 1.5 mm, respectively. The dies were scanned intraorally by the Cerec camera. In order to achieve equally reflecting surfaces, the intraoral areas were covered with scan spray (Dentaco, Bad Homburg, Germany) and/or Vita Cerec powder (Vita Zahnfabrik, Bad Säckingen, Germany). The finish lines of the crowns were virtually designed by determining the margins using the semiautomatic margin finder. In areas where the preparation margin was at the same level as the gingiva, the intensity image method was selected in order to define the margin individually. The adequate basic morphology of the virtual tooth was selected from the tooth library. The occlusal relationship was improved by the help of static and dynamic bite registrations, which also have been scanned in advance. The crowns were milled from IPS e.max CAD LT blanks. After milling, the crowns were tried in by checking the proximal, internal, and occlusal fit. Afterwards, they were sintered and glazed. Due to sintering, the crystalline structure changed from the blue status to a tooth-colored restoration. After the crystallization process, followed by a shrinkage of 0.3%, the crowns were tried in again. In order to document the accuracy of the crowns, replicas were taken, as descibed by Boening et al. [12] and Molin and Karlsson [13]:

The crowns were filled with a light-body silicone (Coltene Affinis light-body, Coltene/Whaledent Inc., Mahwah, NJ, USA) and placed on the abutment teeth applying the same finger pressure on the occlusal surface as used during the insertion of a crown. After setting of the light-body silicone and removing the crown, the thin silicone film that covered the inner contour of the crown was stabilized by injecting a heavy-body silicone into the crowns (Affinis heavy body).

The replicas were then segmented with a razor blade once mesiodistally and three times in buccolingual direction, so that eight segments were obtained (Figs. 1 and 2). The thickness of the light-body silicone was determined as a measure of the discrepancy between the die and the restoration at 50-fold magnification using a light microscope (MM40, Nikon Corp.). The gap widths were measured by moving a reticle from one end of the measuring distance to another. The distances were recorded at four different landmarks using a digital measuring device (Nikon Digital Counter, Nikon Corp.). The landmarks were defined as follows (Fig. 3):

LM1: the marginal discrepancy that represented the marginal gap according to Holmes [14]: The width was measured as the perpendicular distance from the internal surface at the margin of the crown to the preparation.

Table 1 Exemplary studies that investigated the clinical marginal fit of crowns

Authors/ references	Material/System	Median (μm)	Mean	Maximum (μm)	*N*
Wolfart et al. [23]	Heat-pressed lithium disilicate ceramic crown abutments for FDPs (Vivadent-Ivoclar)	96		265	11
Boening et al. [12]rep	Anterior single crowns, alumina oxide (Procera, Nobel Biocare)	90		181	40
	Posterior single crowns, alumina oxide (Procera)	118		228	40
Quante et al. [4]rep	Single crowns				
	Laser sintering of precious alloy (Bego)	72*		178*	14
	Laser sintering of base metal alloy (Bego)	79*		175*	14
Reich et al. [22]rep	three unit all-ceramic FDPs:				
	In-Ceram zirconia (Digident, Girrbach)	75	92	239	16
	Zirconia (Lava, 3 M Espe)	65	80	272	16
	In-Ceram zirconia (InLab, Sirona)	65	77	210	16
	Metal–ceramic, precious alloy (Degunorm, Degudent)	54	67	215	12
Reich et al. [21]rep	Four-unit all-ceramic FDPs zirconia (Lava, 3MEspe)	77	91	406	48

Authors with superscript "rep" applied a similar replica technique. Data with * were extracted from the graph of the respective publication and are approximations

N number of abutments investigated, *FDP* fixed dental prosthesis, median, mean and maximum values when available

LM2: the mid-axial discrepancy that represented the distance between the inner surface of the crown and the die measured at the middle of the axial abutment wall.
LM3: the axio-occlusal transition discrepancy, which was specified as the bisector of the angle, defined between a straight line attached to the occlusal plateau and a straight line applied to the axial wall.
LM4: the mid-occlusal discrepancy (see also Fig. 3).

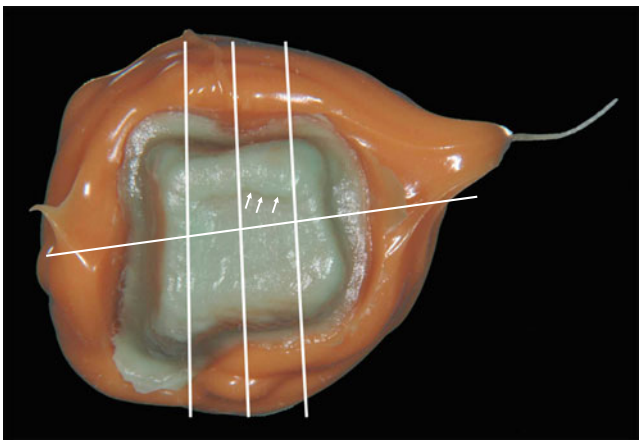

Fig. 1 Molar replica: the crown has been removed. Prior to the removal of the crown, the light-body silicone (*green*; Coltene Affinis light body, Coltene/Whaledent Inc.) was stabilized by a heavy-body silicone (*orange*; Affinis heavy body, Coltene/Whaledent Inc.). Due to the stabilization of the light-body silicone with the heavy-body silicone, the replica could be sectioned by a blade. The white lines indicate the intersections for sample preparation. The white arrows indicate the clearly visible milling path of the 1.6-mm bur, which was used to grind the inner contour

The analyzable number of width values was 160 per landmark at maximum, because 8 cross sections were obtained for each crown. In total, replicas of 30 crowns in 26 patients were available. It is recommended to examine 1 sample per patient. Therefore, in those cases where 2 crowns for 1 patient were manufactured, the replica of one of these crowns was discarded randomly (n=4). One replica had to be discarded because no marginal evaluation was possible (n=1). Due to the fact that the replicas were segmented into 8 cross-sections, a maximum number of eight single values for each landmark per crown could be measured. In order to guarantee a sound data set especially at the margin (LM1), only well-defined measurable locations should be included in the evaluation. Sometimes, the

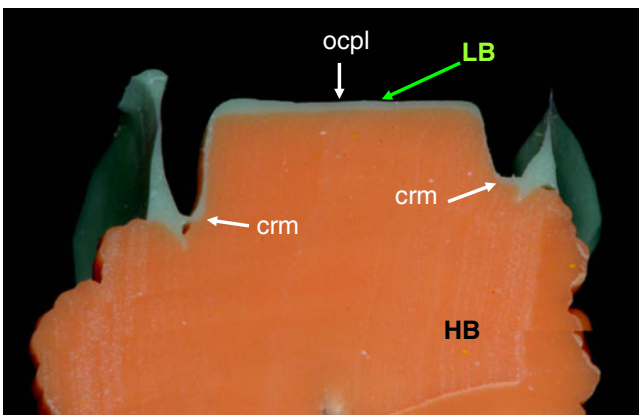

Fig. 2 Transversal slice of a replica. *LB* light-body silicone that represents the discrepancy between the die and the inner surface of the restoration, *HB* heavy-body silicone that stabilizes the light-body silicone, *ocpl* occlusal plateau, *crm* crown margin

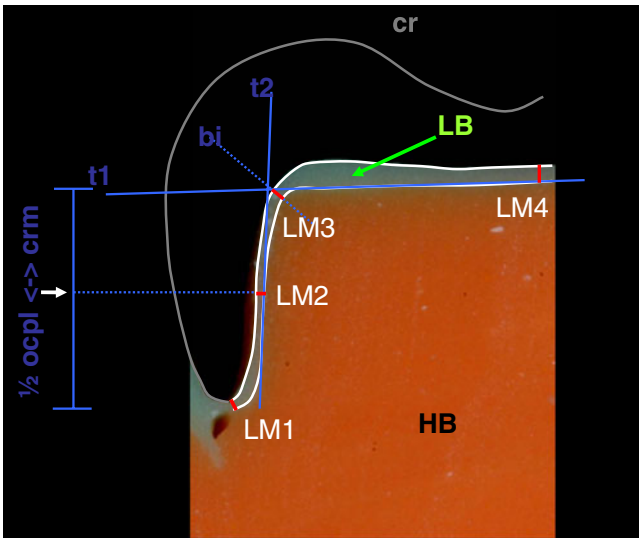

Fig. 3 Segment for measurement. *LB* light-body silicone that represents the discrepancy between the die and the inner surface of the restoration, *HB* heavy-body silicone that stabilizes the light-body silicone, *cr* imaginary crown contour in order to make orientation easier, *1/2 ocpl↔crm* 1/2 distance between the occlusal plateau and the crown margin = mid of the axial abutment wall, *bi* bisector between t1 and t2, *t1* straight line attached to the occlusal plateau, *t2* straight line applied to the axial wall. The landmarks (LM) that were measured at 50-fold magnification are indicated: *LM1* the marginal discrepancy that represented the marginal gap according to Holmes; *LM2* the mid-axial discrepancy represented the distance between the inner surface of the crown and the die measured at the middle of the axial abutment wall; *LM3* the axio-occlusal transition discrepancy, which was defined as the bisector of the angle, defined between a straight line attached to the occlusal plateau (t1) and a straight line applied to the axial wall (t2); *LM4* the centro-occlusally discrepancy

marginal discrepancy (LM1) could not be identified. In order to facilitate an equitable distribution of the LM1 values, all crown replicas were removed from the statistic evaluation where only four or less marginal observations (LM1) per crown were available.

Finally, all available single values of 20 crowns were submitted to the descriptive statistical analysis including the calculation of the 95% confidence interval, which was performed with SPSS (SPSS 11.0, SPSS Corp., Chicago, USA). The *U*-test (Bonferroni corrected) was applied in order to test if there were statistically significant differences between the results of the different landmarks at $p \leq 0.05$.

Results

The largest 95% confidence interval was found at the mid-occlusally landmark (LM4) with a lower bound of 269 μm and an upper bound of 300 μm. At the axio-occlusal transition (LM3) and at the mid-axial wall (LM2), the lower bounds were 213 and 137 μm and the upper bounds were 241 and 158 μm, respectively. The 95% confidence interval for the marginal gaps (LM1) showed a lower bound of 90 μm and an upper bound of 110 μm (Table 2). The null hypothesis was accepted. The mean values, standard deviations, medians, and the minima and maxima of the four landmarks are displayed in Table 2. The lower bounds of the 95% confidence intervals at LM1 of the two examiners were 90 and 91 μm and the upper bounds were 106 and 113 μm, respectively. The distribution of all measured values at LM1 collected into groups revealed $n = 100 \leq 120\mu$m, $n = 17 \leq 160\mu$m, $n = 6 \leq 200\mu$m, $n = 11 \leq 300\mu$m, and $n = 1 \leq 350\mu$m.

The median values of all four landmarks differed significantly from each other (*U*-test, Bonferroni corrected) at $p \leq 0.05$.

Discussion

A good marginal fit of a crown is still one of the decisive criteria whether a restoration can be inserted. In the current study, the replica technique was used to evaluate the clinical accuracy of chair-side CAD/CAM generated lithium disilicate crowns. One major advantage is the nondestructive character of the replica technique. According to an in vitro investigation by Rahme et al. [15], the use of a low-viscosity silicone for the replica technique seemed to imitate the film thickness of a cemented crown applying glass-ionomer cement. Tsitrou et al. [16] investigated the film thicknesses of a light-body silicone and resin composite for crown cementation. They revealed mean marginal gaps between 91 and 105 μm and between 75 and 102 μm, respectively. In this study, the preparation design, chamfer or step preparation, had no significant influence on the gap width. McLean and von Fraunhofer [6] and Fransson et al. [9] stated that the replica technique simulates the flow properties of zinc phosphate cements. For zinc phosphate cements, a cement space of at least 20 to 40 μm should be provided [17].

The reliability and validity of the replica method were confirmed by several authors [15, 18]. Shortcomings of the replica method are the two-dimensional display of a marginal gap and, in some cases, the interpretation of this gap, especially if a margin is located subgingival [12]. In the current study, some replicas had to be discarded because the interpretation at LM1 was not possible. Due to the fact that a certain variance of the seating force has no impact on the film thickness, finger pressure was applied [19]. Weaver at al. [19] revealed a mean seating force of 8 kg (=78.5 N) with a standard deviation of 1.3 kg (=12.75 N). From a clinical point of view, the insertion of single crowns with finger pressure facilitates a better controlled insertion than a "standardized" force application with the lever of a dynamometer, especially in the posterior region. Of course,

Table 2 Results of cement thickness gap measurements for CAD/CAM lithium disilicate crown fits in patients (n=20)

Landmark	Mean (μm)	SD (μm)	95% confidence interval		Minimum (μm)	Q25	Median (μm)	Q75	Maximum (μm)
			Lower bound (μm)	Upper bound (μm)					
LM1	100	61	90	110	28	57	81	124	343
LM2	148	61	137	158	27	98	138	180	299
LM3	227	83	213	241	30	173	221	273	554
LM4	284	95	269	300	81	229	273	319	642

The median values of all landmarks revealed statistically significant differences from each other, applying the *U*-test (Bonferroni corrected) at $p \leq 0.05$

SD standard deviation, *Q25* 25th percentile, *Q75* 75th percentile, *LM1* the marginal discrepancy, *LM2* the mid-axial discrepancy, *LM3* the axio-occlusal transition discrepancy, *LM4* discrepancy centro-occlusally

the forces applied by a patient biting on a cotton roll may exceed the values of finger pressure, but they may vary in a wide range from patient to patient.

The results of the study showed that it is possible to process chair-side crowns that exhibit marginal gaps below 120 μm with respect to the upper bound of the 95% confidence interval, using the Cerec system. The lower bound was 90 μm. The minimum thicknesses were 28 and 27 μm at LM1 and LM2, respectively. This value is similar to the range of a die spacer, which was deemed to be about 24 μm and was used in laboratory trials by Wang et al. They found that a die spacer significantly improved the seating of metal alloy crowns cemented with glass-ionomer or zinc phosphate cements when a seating force of about 13.6 kg was applied [20]. In general, the cement thickness of glass-ionomer cements revealed lower values than those of zinc phosphate cements, which could have contributed to the different flow properties of the two cements. In comparison to the zinc phosphate cement, the viscosity of a glass-ionomer cement remains constant before setting. The margin geometry may also influence the seating of a cemented crown. A shoulder bevel facilitates a better seating than a shoulder [20], but the preparation for a lithium disilicate ceramic requires the shoulder or a pronounced chamfer. In case of conventional cementation of a lithium disilicate crown, the glass-ionomer cement would be the material of choice.

According to the authors' knowledge, there is no other study that evaluated the accuracy of chair-side generated lithium disilicate ceramics. The marginal values of the present study are in the same range, compared to other clinical studies [12, 21–23] (Table 1). On the one hand, the study revealed that it is possible to achieve crowns with marginal gap widths below 120 μm in all 8 replica segments (5 crowns), but there were also 5 crowns that showed one or two values between 160 and 300 μm. However, similar or even higher maximum values are obtained in other studies [12, 23] as well.

The increasing discrepancies at LM2, LM3, and LM4 can be attributed partially to the geometry of the milling burs since the diameter of the milling bur determines the smallest grindable radius of the inner crown contour. The arrows in Fig. 1 indicate the traces of the 1.6-mm-diameter bur that was used for milling the inner contour. Meanwhile, step burs with a diameter of 1.0 mm are available. Another possible reason for high internal deviations are the so-called "overshooters" that simulate virtual peaks near the edges of three-dimensional structures when they are captured from digital scanning [24].

Due to recent developments in the field of intraoral capturing techniques such as using blue light striation projection (Cerec AC, Sirona) or active wave front sampling (Lava COS, 3 M Espe, St. Paul, USA), it would be of practical interest to evaluate if the latest innovations that are marketed as improved techniques have a significant impact on the clinical outcome.

However, the results that were revealed at the margin (LM1) in this study are within an acceptable range so that a conventional cementation could be considered for single crowns, if an adhesive insertion is not possible due to absence of absolutely dry conditions. The null hypothesis that the upper bound of the 95% confidence would be below 120 μm could be accepted.

Conclusion

Within the limitations of the present study, it can be concluded that with the present conventional cementing techniques, it is possible to approach the clinically acceptable target for a marginal gap limit of 120 μm.

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Conflict of interest Dr. Reich did an oral presentation by order of Ivoclar-Vivadent and received a fee.

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